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of

THE ROYAL AERONAUTICAL SOCIETY

OCTOBER 1960

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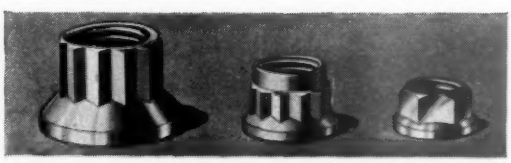

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Journal of

THE ROYAL AERONAUTICAL SOCIETY

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

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All communications for publication in the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., F.R.Ae.S., Hon.F.C.A.I., F.I.A.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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NOTICES

Honours Awarded to Members

Lord Hives (*Honorary Fellow*) has been awarded the Churchill Gold Medal by The Society of Engineers.

Igor I. Sikorsky (*Honorary Fellow*) Engineering Consultant, Sikorsky Aircraft, Division of United Aircraft Corp., was awarded the Grover E. Bell Award at the Honors Night dinner of the American Helicopter Society's 16th Annual Forum.

Igor Alexis Sikorsky (*Associate Fellow*), Chief Aerodynamicist, Sikorsky Aircraft, Division of United Aircraft Corp., has been named an Honorary Fellow of the American Helicopter Society.

Representatives on Other Bodies

Sir A. H. Roy Fedden (*Honorary Fellow*) and Sir Harold Roxbee Cox (*Fellow*) have been appointed for a further term of office as the Society's Representatives on the Governing Body of the College of Aeronautics, Cranfield.

Conference on Irreversibility and Statistical Mechanics

The Institute of Physics and the Physical Society will hold a conference on statistical mechanics (with special reference to irreversibility), at Queen Mary College, London, on 19th and 20th December 1960. The topics include the general theory of irreversibility, random processes, liquids (theory and experiment) and irreversibility in gases and in plasma.

Further information and preliminary programmes may be obtained from The Secretary, The Institute of Physics and The Physical Society, 47 Belgrave Square, S.W.1.

Refresher Courses for Engineers and Scientists in Industry

The Ecole Nationale Supérieure de l'Aéronautique is organising special courses of lectures during 1960-61, so that applicants who left college some years ago can be brought up to date with recent developments.

Details on the subjects to be covered, costs and dates of courses and data on registration formalities may be obtained from M. le Directeur de l'Ecole Nationale Supérieure de l'Aéronautique (Direction des Stages), 32 Boulevard Victor, Paris 15e.

Courses in Aeronautical Engineering Practice

The City and Guilds of London Institute has prepared a revised scheme of courses and examinations which supersedes the present courses 172-175.

The scheme is designed to provide four-year part-time courses for those apprentices and craftsmen with suitable educational backgrounds who may aspire to advancement in the industry, and covers the following industrial requirements:—

171. Aircraft Production—Power Plant
172. Aircraft Production—Airframes
173. Aircraft Maintenance—Power Plant
174. Aircraft Maintenance—Airframes
175. Aircraft Electrical Practice

The new scheme will come into force in technical colleges for the 1960/61 session and the first examinations will be held in 1961. A pamphlet giving particulars of the scheme may be obtained from the City and Guilds of London Institute, 76 Portland Place, London W.1 (price one shilling including postage).

The Sixteenth British Commonwealth Lecture

The Sixteenth British Commonwealth Lecture, "The Story of Indian Air Transport," will be given by Mr. J. R. D. Tata, Chairman, Air-India International, on Friday 18th November at 6 p.m. in the new Lecture Theatre, 4 Hamilton Place, W.1. Tea will be served at 5.30 p.m.

The Short Brothers Commemorative Lecture

The First Short Brothers Commemorative Lecture will be given by Mr. J. Lankester Parker, O.B.E., F.R.Ae.S., Hon.M.S.L.A.E., on Thursday 20th October at 7 p.m. in Lecture Hall LG25, David Keir Building, Queen's University, Belfast.

Supplement to the Oxford English Dictionary

The following is the ninth list of aeronautical terms for the Supplement to the Oxford English Dictionary for which assistance in tracing earlier references is required. If members know of an earlier use than that given for any word in the following list they are asked to write to the Editor, Oxford English Dictionary Supplement, 40 Walton Crescent, Oxford, giving the reference(s), date, author, title, chapter and page. Earlier lists have been published in alternate numbers of the Journal since June 1959 and thanks are expressed to those who have already responded to these appeals.

downwash, sb. (aeronautics)	1915	*Rep. & Memoranda Advisory Comm. for Aeronautics, No.* 196
drag, sb. (aeronautics)	1909	*Engineering Wonders of the World*
drogue (air target)	1931	*Flight*, 13th March
drogue (parachute)	1947	*Times*, 30th August
drogue (refuelling funnel)	1949	*Flight*, 11th August
drogue (sea-plane anchor)	1919	W. B. Faraday (ed.), *Glossary of Aeronautical Terms*
drogue (wind-sock)	1932	*Nuttall's Standard Dictionary (Supplement)*
dropping zone	1945	*By Air to Battle* (H.M.S.O.)
dummy run (air bombing)	1943	C. H. Ward-Jackson, *It's a Piece of Cake*
E/A (=enemy aircraft)	1916	T. E. Lawrence, *Letters*
E.T.A. (=estimated time of arrival)	1939	*Flight*, 26th October
ejection seat (in aircraft)	1945	*The Aeroplane*, 16th November
ejector seat	1945	*Flight*, 15th November
eleron	1946	*Aircraft Recognition Journal*
envelope, sb. (of airship)	1909	*Rep. Advisory Comm. for Aeronautics*
escape hatch	1933	*Jane's Fighting Ships*

Aircraft Gas Turbine Theory and Design

A short course on Aircraft Gas Turbine Theory and Design will be held at The College of Aeronautics from 7th to 25th November 1960, dealing mainly with performance, systems, turbomachine aerodynamics and related design topics, but including some experimental work on engines.

Fees for the course are £70 inclusive of full board and residence. Further details and enrolment forms may be obtained from the Warden, The College of Aeronautics, Cranfield, Bletchley, Bucks.

DIARY

MAIN SOCIETY

All lectures in London will be held in the Lecture Theatre, 4 Hamilton Place, unless otherwise stated.

20th October

Main Lecture at Belfast Branch—First Short Brothers Commemorative Lecture. J. Lankester Parker. **Lecture Hall LG25, David Keir Building, Queen's University, Belfast. 7 p.m.**

11th November

Joint Lecture with the Institution of Electrical Engineers. The Future of Electrics and Electronics in Aircraft and Guided Missiles. The Rt. Hon. The Viscount Caldecote. **Savoy Place, Victoria Embankment, W.C.2. 5.30 p.m.** (Tea at 5 p.m.)

18th November

Sixteenth British Commonwealth Lecture—The Story of Indian Air Transport. J. R. D. Tata. **6 p.m.** (Tea at 5.30 p.m.)

21st November
HISTORICAL GROUP—My First Ten Years in Aviation. Sir Thomas Sopwith. **7 p.m.**
22nd November
Basic Aerodynamic Considerations of V/STOL Aircraft. P. L. Sutcliffe. **7 p.m.**
28th November
AGRICULTURAL AVIATION GROUP—The Farmer's Viewpoint. J. B. Farrant. **7 p.m.**
30th November
MAN POWERED AIRCRAFT GROUP—Some Aspects of Bird Flight. John Barlee. **7 p.m.**

GRADUATES' AND STUDENTS' SECTION

23rd November
The British Space Programme. M. O. Robins. **7.30 p.m.**
25th November
Annual Dance. 8 p.m.

BRANCHES

10th October
Boscombe Down—Vertical Take-Off by Jet Lift. D. Keith-Lucas. Lecture Hall, A. & A.E.E. 5.30 p.m.
Henlow—Fifty Years in the Aircraft Industry. Sir Frederick Handley-Page. Assembly Hall, R.A.F. Technical College. 7.45 p.m.
11th October
Luton—Film Evening. Napier Senior Staff Canteen, Luton Airport. 6 p.m.
12th October
Brough—An Air Bridge for Hull. M. G. K. Byrne. Royal Station Hotel Writing Room, Hull. 7.30 p.m.
London Airport—The V.C.10. Hugh Hemsley. Senior Mess, B.O.A.C. H.Q., London Airport. 6 p.m.
13th October
Glasgow—Symposium—Installation Problems in Modern Aircraft: From the Engine Designer's Point of View, F. W. Morley; From the Aircraft Manufacturer's Point of View, G. H. Lee; From the Aircraft User's Point of View, R. C. Morgan. Rolls-Royce Factory, East Kilbride. 7.15 p.m.
15th October
Halton—Annual General Meeting. 4 p.m. Followed by History and Development of Martin Baker Ejection Seats, Wing Cdr. J. Jewell. 5 p.m. Branch Hut, R.A.F. Halton. Annual Dinner, The Bull's Head Hotel, Aylesbury.
19th October
Southend—Rocket Engines. L. S. Snell. Room 3, Engineering Dept., Municipal College, London Road. 7.30 p.m.
20th October
Belfast—MAIN SOCIETY LECTURE—First Short Brothers Commemorative Lecture. J. Lankester Parker. Lecture Hall LG25, David Keir Building, Queen's University. 7 p.m.
Isle of Wight—Experiences in the Trans-Antarctic Expedition. Wg. Cdr. J. H. Lewis. Saunders-Roe Clubhouse, E. Cowes. 6 p.m.
26th October
Christchurch—Flying with the Antarctic Expedition. Wg. Cdr. J. H. Lewis. King's Arms Hotel. 7.30 p.m.
Coventry—Model Testing in the A.R.A. Wind Tunnel. E. C. Carter. Herbert Art Gallery. 7.30 p.m.
Weybridge—Film Show. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6 p.m.
31st October
Boscombe Down—Background for Space Travel. A. F. Collins. Lecture Hall, A. & A.E.E. 5.30 p.m.
Henlow—Student Members' Papers. Assembly Hall, R.A.F. Technical College, Henlow. 7.45 p.m.
2nd November
Swindon—The Radio Telescope. Dr. J. Davis. The College, Victoria Road, Swindon. 7.30 p.m.
3rd November
London Airport—Helicopters. Peter Brooks. Lecture Hall, Fairey Aviation Co., Hayes. 6.15 p.m.
9th November
Brough—Seventh Sir George Cayley Memorial Lecture. Forty Yeaas of Aviation Journalism. Major Oliver Stewart. Royal Station Hotel Writing Room, Hull. 7 p.m.
10th November
Isle of Wight—Annual Dinner. Royal Squadron Hotel, Ryde.
14th November
Henlow—Accident Investigation. P. G. Tweedie. Assembly Hall, R.A.F. Technical College, Henlow. 7.45 p.m.
15th November
Luton—Certification of Aircraft in the U.S.A. K. H. Greenly. Napier Senior Staff Canteen, Luton Airport. 6 p.m.
16th November
Christchurch—The Design of the C.N.7 and the New Land Speed Record. L. H. Norris and K. H. Norris. King's Arms Hotel. 7.30 p.m.
Coventry—Flight Development of Modern Production Aircraft. C. F. Bethwaite. Herbert Art Gallery. 7.30 p.m.
Southend—Film Show (including "Antarctic Crossing"). Room 3, Engineering Dept., Municipal College, London Road. 7.30 p.m.
17th November
Cheltenham—Air Traffic Control. F. J. Low. St. Mary's College, St. Georges Place, Cheltenham. 7.30 p.m.
23rd November
Weybridge—Joint Meeting with the Southern Branch of the Institution of Mechanical Engineers. The Art of Developing Aero Engines. A. C. Lovesey. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6 p.m.

ASSOCIATE FELLOWSHIP EXAMINATION RESULTS

The following candidates were successful in the Associate Fellowship Examination held in June 1960:—

PART I—UNITED KINGDOM

A. J. GIDYNSKI. Strength of Aircraft Materials and Theory of Structures, Thermodynamics.

F. A. KHAN. Strength of Aircraft Materials and Theory of Structures, Thermodynamics.

B. B. NIGAM. Theory of Machines.

P. G. PINNEY. Aerodynamics, Strength of Aircraft Materials and Theory of Structures.

A. J. ROSS. Aerodynamics, Strength of Aircraft Materials and Theory of Structures.

R. K. SATJADIBRATA. Pure Mathematics, Mechanics, Physics, Strength of Aircraft Materials and Theory of Structures, Theory of Machines; E. J. SAUNDERS. Aerodynamics, Strength of Aircraft Materials and Theory of Structures.

PART I—ABROAD

S. P. CHAUDHARY (Kanpur). Pure Mathematics, Mechanics, Physics, Thermodynamics.

P. M. GOYAL (Poona). Pure Mathematics, Mechanics, Physics, Strength of Aircraft Materials and Theory of Structures.

K. K. KHANNA (Delhi). Strength of Aircraft Materials and Theory of Structures, Thermodynamics.

O. M. P. MALHOTRA (Calcutta). Thermodynamics.

Y. K. NAGARAJA (Bangalore). Aerodynamics; N. NEWMAN (Sydney). Pure Mathematics, Mechanics, Physics, Thermodynamics, Theory of Machines.

K. P. RAMASWAMY (Bombay). Mechanics, Thermodynamics; A. R. ACHYUTHA RAO (Bangalore) Mechanics, Aerodynamics.

J. T. THORPE (Hong Kong). Aerodynamics, Theory of Machines.

H. CHAND UPPAL (Jodhpur). Pure Mathematics, Mechanics, Physics, Aerodynamics, Thermodynamics.

PART II—UNITED KINGDOM

R. F. BARTON. Theory of Structures A, Theory of Structures B, Theory of Structures C, Aircraft Design and Development A; R. T. BULLUS. Theory of Structures B, Aircraft Design and Development B.

A. DEANE. Theory of Structures A, Theory of Structures B, Theory of Structures C.

G. GREENFIELD. Theory of Structures A, Theory of Structures B, Theory of Structures C.

G. HEMSLEY. Theory of Structures B; I. B. HUDSPITH. Theory of Structures B.

J. W. KNIGHT. Theory of Structures A, Theory of Structures B, Thermodynamics and Theory of Machines.

M. MILLARD. Theory of Structures A, Theory of Structures B, Theory of Structures C, Aircraft Design and Development A, Aircraft Design and Development B; R. MURRAY. Theory of Structures A, Theory of Structures B, Theory of Structures C.

D. O. REID. Theory of Structures A, Theory of Structures B, Theory of Structures C, Economics and Management.

Z. A. SIDDIQI. Thermodynamics and Theory of Machines, Economics and Management.

PART II—ABROAD

A. S. DHILLON (Kanpur). Thermodynamics and Theory of Machines, Piston and Turbine Engines.

V. GOVINDAN (Bangalore). Thermodynamics and Theory of Machines, General Design Piston and Turbine Engines, Piston and Turbine Engines.

N. NEWMAN (Sydney). Thermodynamics and Theory of Machines, Piston and Turbine Engines.

V. A. OGALE (Bangalore). Thermodynamics and Theory of Machines, General Design Piston and Turbine Engines, Piston and Turbine Engines.

P. M. RAMACHANDRAN (Bombay). Theory of Structures A, Aircraft Design and Development A.

J. T. THORPE (Hong Kong). Air Transport, Meteorology, Operational Air Transport.

J. G. WILSON (Ontario). Meteorology.

NEWS OF MEMBERS

Plt. Officer K. L. ARORA (*Graduate*) formerly Flight Mechanic (Engines) I.A.F. Kanpur, is now Engineering Officer of 51 Aux. Air Squadron, Janpath, New Delhi.

J. R. BATT (*Associate*) formerly Group Chief Inspector of Aviation Traders (Eng.) Ltd., is now Technical Director.

R. BEANEY (*Associate Fellow*) formerly Experimental and Development Manager of Short Brothers and Harland Ltd., Belfast, has been appointed Aircraft Service Manager.

W. L. BENNETT (*Associate Fellow*) formerly Flight Engineering and Technical Supt. (Flight Ops.) has been appointed Manager, Line Maintenance, B.O.A.C.

R. J. BICKFORD (*Associate Fellow*) formerly at A. & A.E.E., Boscombe Down, has been posted to the Division of R.A.F. Aircraft, Research and Development, H.Q., Ministry of Aviation.

C. B. BOLTON (*Associate Fellow*) formerly in the Mechanical Engineering Department, R.A.E. Farnborough, has been posted to Linton-on-Ouse as Officer Commanding Provost Servicing and Ground Engineering Squadron, with the acting rank of Squadron Leader.

J. W. BUGLER (*Associate Fellow*) formerly Meteorological Officer of H.M.S. Centaur, is now Lecturer in Aerodynamics at the Royal Naval Engineering College, Manadon, Plymouth.

Lt. Cdr. F. A. BURLS (*Associate Fellow*) has retired from the Royal Navy and is now Production Planning Engineer at Cowans, Sheldon and Co. Ltd., Carlisle.

Group Capt. R. E. BURNS (*Associate Fellow*) formerly Commandant, Empire Test Pilots' School, Farnborough, is now R.A.F. Representative to the Federal Aviation Agency, New Jersey, U.S.A.

W. G. S. CASTLE (*Student*) formerly Design Office (Technical) Ransome and Marles Ltd., Newark, Notts., is now with Rolls-Royce and Associates Ltd. as Installation Engineer, Derby.

M. G. CHERRY (*Graduate*) formerly Preliminary Design Engineer, AiResearch Manufacturing Co., Los Angeles, is now a Design Engineer, Aerojet General Corp., Azusa, Calif.

Sqn. Ldr. R. CHRISTIE (*Associate Fellow*) formerly on the Staff of the R.A.F. Technical College, is now with the Directorate of Flight Safety, Air Ministry.

Sqn. Ldr. C. J. T. COOMBS (*Associate Fellow*) formerly Education Branch, R.A.F. Seletan, Singapore, is now Senior Physics Instructor at the R.A.F. College, Cranwell.

P. J. DAGLISH (*Associate Fellow*), formerly Assistant to the Chief Engineer, D. Napier and Son Ltd., has been appointed Special Executive responsible to the Managing Director.

H. DEACON (*Associate Fellow*) formerly Education Officer at Handley Page Ltd., is now Senior Lecturer at Hatfield Technical College.

W. C. DEE (*Associate*) formerly Technical Sales Engineer with E.M.O. Ltd., Bracknell, is now Technical Sales Manager, Micro Turbines Ltd., Cheshunt.

Sir GEORGE EDWARDS (*Hon. Fellow*) has been elected Vice-Chairman of the Board of Hunting Aircraft Ltd.

L. G. FAIRHURST (*Fellow*) formerly Technical Director, Dowty Rotol Ltd., is now Chief Mechanical and Hydraulics Engineer, English Electric Aviation, Warton.

Sqn. Ldr. F. FALLAN (*Associate Fellow*) formerly Officer Commanding Engineering Squadron, R.A.F. Valley Anglesey, is now in C.A.S.L.O., Ministry of Aviation.

E. J. FARROW (*Associate Fellow*) formerly Sales Engineer, Babcock and Wilcox is now a Lecturer in Mechanical Engineering at Watford Technical College.

Air Cdre. A. A. F. HICKMAN (*Associate Fellow*) formerly Senior Technical Staff Officer, Middle East Air Force, is now Director of Technical Training, Air Ministry.

R. C. HINTON (*Associate Fellow*) formerly Senior Inspector (Eng. II) Inspector of Armaments, M.o.A., Woolwich, is now with the United Kingdom Defence, Research and Scientific Staff, W.R.E., Salisbury, S. Australia.

R. M. HOLLOCK (*Associate Fellow*) formerly Assistant General Manager, Scottish Aviation Ltd., is now Manager (Warton) English Electric Aviation Ltd.

J. HOMFRAY (*Student*) formerly at the College of Aeronautics, has obtained his D.C.Ae. and is now a Wind Tunnel Technician, Sir W. G. Armstrong Whitworth Aircraft Ltd., Coventry.

F. IRELAND (*Graduate*) formerly Development Engineer, Fuel Systems, Joseph Lucas Equipment Ltd., is now Experimental Officer, W.R.E., Salisbury, S. Australia.

L. E. JONES (*Associate*), formerly Sales Manager, R.F.D. Company (Australia) Pty. Ltd., Melbourne, is now General Manager and a Director.

J. C. KING (*Associate Fellow*) formerly with English Electric Co. Ltd., Phoenix Works, Bradford, is now Manager, Aircraft Equipment Division.

D. C. KOHLI (*Graduate*) formerly Senior Scientific Officer at the National Aeronautical Laboratory, New Delhi, is now a Structural Engineer, Hindustan Motors Ltd., Calcutta.

Group Capt. S. W. LANE (*Associate Fellow*) formerly Chief, Maintenance Division, H.Q. Allied Air Forces Central Europe, is now Chief Aircraft Supplies Liaison Officer, Ministry of Aviation.

ECKART LEMBERG (*Associate Fellow*) formerly Design Engineer, Stanley Aviation Corp., Denver, is now a Project Engineer with Ball Brothers Research Corp., Boulder, Colorado.

D. M. H. LOWE (*Associate Fellow*) formerly with Canadair Ltd., Montreal is now Technical Assistant to the Chief Systems Test Dept., Field Operations, Aero Space Division, Boeing Airplane Company, Seattle.

P. J. MARSH (*Associate Fellow*) formerly Structural Development Test Engineer with Vickers-Armstrongs (Aircraft) Ltd., is now with Canadian Pratt and Whitney Ltd., Montreal.

MAURICE W. MARTIN (*Associate Fellow*) formerly a Production Development Engineer with Hawker Aircraft Ltd., is now Senior Planning Engineer with Hawker Siddeley Aviation Ltd., Advanced Projects Group.

R. E. MILLS (*Associate Fellow*) formerly Design Engineer in charge of the London Office, H. M. Hobson Ltd., is now Chief Designer, S. E. Opperman Ltd., Boreham Wood.

H. A. MONEY (*Graduate*) formerly Stressman, Folland Aircraft Ltd., is now a Research and Development Engineer, Berkeley Nuclear Laboratories, Central Electricity Generating Board.

K. J. OLDHAM (*Associate Fellow*) formerly Section Leader Performance Engineer, Vickers-Armstrongs (Aircraft) Ltd., Weybridge, has joined Trans-Canada Airlines in Winnipeg.

A. G. PAYNE (*Associate Fellow*) formerly with H.M. Overseas Civil Service as Principal, Government Technical Institute, Georgetown, British Guiana, is now Principal, Bridgewater Technical College, Somerset.

J. PICKLES (*Associate Fellow*) formerly a Designer with the English Electric Co. Ltd., Warton, is now Senior Designer with the Lancashire Aircraft Co. Ltd., Samlesbury Airfield, Nr. Blackburn.

J. T. POCOCK (*Student*) formerly Structural Engineer, Vickers-Armstrongs (Aircraft) Ltd., is now Assistant Mechanical and Electrical Engineer, British Phosphate Commissioners, Christmas Island.

Flt. Lt. J. A. PORTER (*Graduate*) formerly Engineer Officer No. 151 Squadron, R.A.F. Leuchars, is now Radio Trials Officer, A. & A.E.E., Boscombe Down.

Flg. Officer D. W. RUMBOLD (*Student*) has graduated from R.C.A.F. Aeronautical Engineering School at Aylmer, Ontario, and is now a Test Co-ordinator, R.C.A.F. Air Material Laboratory, Ottawa.

E. STADDON (*Associate*) formerly a Design Draughtsman with Fairey Engineering Ltd., Stockport, is now a Design Draughtsman, Guided Weapon Drawing Office, Ferranti Ltd., Manchester.

Sqn. Ldr. R. H. TAYLOR (*Associate Fellow*) formerly of the Trials Wing, R.A.F. North Coates, is now at the Ministry of Aviation, Headquarters in D.G.W. (Air).

Flt. Lt. D. A. WARD (*Associate Fellow*) formerly Technical Officer, Technical Branch, Advanced Guided Weapons Course, R.A.F. Technical College, Henlow, is now at the Royal Radar Establishment, Great Malvern.

Wg. Cdr. G. H. WASS (*Associate Fellow*) is motoring to Jordan via Lebanon and Syria with Mrs. Wass on a mission to raise funds and to start several Cheshire Homes for Incurables in Lebanon, Jordan and possibly Kuwait.

R. H. WEIR (*Fellow*), formerly Director-General of Engine Research and Development, has been appointed Director of the N.G.T.E., Pyestock.

C. A. WILLIAMS (*Associate Fellow*) formerly Chief Instructor, Aviation Training Unit, Smiths Aircraft Instruments Ltd., now has a teaching appointment in Electrical Engineering at the Forest of Dean Mining and Technical College, Glos.

J. WISEMAN (*Associate*), Group Engineering Manager of Aviation Traders (Eng.) Ltd., has been appointed to the Board.

F. H. WOOD (*Associate*) formerly Research Engineer, S. Smith and Sons (Canada) Ltd., Toronto, is now with Elliott Bros., Boreham Wood.

Sqn. Ldr. D. A. S. WOODBRIDGE (*Associate Fellow*) formerly O.C. Ground Engineering Squadron, R.A.F. Cottesmore, is now O.C. Engineering Squadron, R.A.F. Anglesey.

H. M. WOODHAMS (*Fellow*) has retired from his appointments as Chairman and Managing Director of Sir W. G. Armstrong Whitworth Aircraft Ltd., and Director of Hawker Siddeley Aviation Ltd., but will remain on the Board of Sir W. G. Armstrong Whitworth Aircraft Ltd.

Flt. Lt. D. WOODS (*Associate Fellow*) formerly Officer I/C R.S.F., R.A.F. Seletar, is now with the Mechanical Engineering Department, R.A.E. Farnborough.

Lecture Summaries

The First Short Brothers Commemorative Lecture

A TRIBUTE TO THE THREE BROTHERS

J. LANKESTER PARKER

To be given before the Belfast Branch on 20th October 1960

Included among the select few pioneers of mechanical flight are the three Short brothers—Horace Leonard, Albert Eustace and Hugh Oswald, who founded a company in 1908 with a capital of £600 for the sole purpose of manufacturing aircraft. But this was not their first connection with aviation for the two younger brothers had been building balloons and making ascents in them for some years and by 1903 had been appointed official balloon makers to the Aero Club.

The lecturer traces the early history of the Company, its move to Shellbeach in the Isle of Sheppey where their works are generally believed to have been the first factory in the world devoted to the building of aircraft, the move to Rochester on the banks of the Medway as seaplanes became more and more important, and then the move to Belfast Lough, Northern Ireland, the present home of the Company. The lecturer refers to many of the aeroplanes built by the Company, the many "firsts" in aviation attributed to the Short brothers—whom he knew intimately since 1916—and concludes with an account of the personalities of the three brothers, each a genius in his own way.

(*This lecture will be published*).

Sixteenth British Commonwealth Lecture

THE STORY OF INDIAN AIR TRANSPORT

J. R. D. TATA

On 18th November 1960

After noting that the first official carriage of mail by aeroplane took place in India in 1911, Mr. Tata traces the history of Indian air transport from its beginnings in December 1931, when the Delhi Flying Club temporarily took over the carriage of mail from Karachi to Delhi from Imperial Airways, to the present day, when all scheduled air transport operations are centred in two State-owned Corporations.

The paper roughly divides the story of air transport into two main periods: from the early 'thirties until 1946, and from 1946 to the present day. In the first period the paper highlights the fact that, while permitting Dutch and French airlines to operate continuous services of their own across India to the East Indies and Indo-China, the then British administration in India hindered the normal development of the British Imperial Airlines by insisting on separate Indian participation in the U.K.-Australia service.

In the second part, the lecturer describes in some detail the rapid but uneconomic growth of Indian air transport based on the availability, at negligible cost, of surplus war-time Dakotas and the unsound operation of a licensing system under which far too many companies were licensed, each with inadequate traffic and route mileage. As a result, the industry suffered increasingly heavy losses until 1953 when the Government of India nationalised all scheduled operations and incorporated them into two State Corporations.

After analysing the pros and cons of nationalisation, Mr. Tata describes the rapid growth of both State Corporations and the difficult but successful integration and unification of eleven separate organisations.

Finally, the paper refers to India's entry into the jet age, compares Indian operations with those of other countries, refers to the recent trend towards pooled operations in the international field, and concludes with a brief survey of future developments and prospects in India and the world as a whole.

(*This lecture will be published*).

Historical Group

MY FIRST TEN YEARS IN AVIATION

SIR THOMAS SOPWITH, C.B.E., Hon.F.R.Ae.S.

On 21st November 1960

Sir Thomas Sopwith looks back on his first ten years with stick-and-string aeroplanes which in fifty years led to the great Hawker-Siddeley Group. He tells how a glimpse of the first aeroplane flying from Paris to London in 1910 fired his imagination and he decided to fly too. He taught himself to fly in a month and, three weeks later, won the £4,000 de Forest prize. With that and prize money he won in America in 1911 he formed the Sopwith Aviation Co.

Sir Thomas tells amusing anecdotes of how such words as "taxi-ing" and "strafe" came into the international language of aviation, and of his early air racing.

When war came in 1914 his firm had nine types ready for service and then he, his engineer Fred Sigrist and test pilot Harry Hawker, designed and built fighters that are now legendary—the One-and-a-half-strutter, Pup, Camel, Tripehound, Snipe and others.

When the war ended and orders were cut off they carried on for a year or two, but it was obvious that the firm could not carry on with its huge factories standing idle so Sopwith told his board they must wind up while still solvent, which they did. A new company was formed and named after Hawker as a tribute to his great work as test pilot and to avoid confusion with the defunct Sopwith Company, to build aircraft when there was a need, and make domestic appliances, motor-cycles and other things.

(*This lecture will be published*).

The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 64 OCTOBER 1960 NUMBER 598

Research at the College of Aeronautics Cranfield

by

PROFESSOR A. J. MURPHY, M.Sc., F.R.Ae.S., F.I.M.

(*The Principal, College of Aeronautics*)

and THE STAFF OF THE COLLEGE

The 1,142nd lecture to be given before the Society and the 37th Main lecture to be held at a Branch Centre "Research at the College of Aeronautics" by Professor A. J. Murphy, M.Sc., F.R.Ae.S., F.I.M., Principal, College of Aeronautics, was given under the auspices of the Cambridge Branch on 21st January 1960. Professor W. A. Mair, M.A., F.R.Ae.S., Francis Mond Professor of Aeronautical Engineering, University of Cambridge, and President of the Cambridge Branch, opened the proceedings and then handed over to the President of the Society, Mr. Peter G. Masefield, M.A., F.R.Ae.S., Hon.F.I.A.S., M.Inst.T.

Mr. Masefield: As an old Cambridge engineering man it was a great pleasure to be President of the Society in the year in which the first Main lecture was held at Cambridge.

One of the most important and significant developments in aeronautical education since the war had been the founding, and the progress in recent years under Professor Murphy, of the College of Aeronautics at Cranfield. It had been founded just after 1944 as a result of the Fedden Committee of that year, set up by Sir Stafford Cripps, then Minister of Aircraft Production. Cranfield was primarily concerned with two things: post-graduate training in all branches of aeronautics and associated sponsored research by both staff and students of the College. Professor Murphy was to speak on the latter part.

British aeronautics today was passing through one of those periodic upheavals which seemed to happen every few years in this great business in which so many of them were engaged. Some of the changes now in progress he thought could mean a great difference in British aviation in the 50 years to come, compared with the 50 years that had gone by, and many of them he hoped would be concerned in these changes and in the new era of British aviation which was just beginning. He hoped that 1960 would mark the beginnings of a new chapter in aviation history as 1910 had done fifty years ago.

Over the past 50 years about 85 per cent of work in aeronautics in Great Britain had been in the military field; certainly 85 per cent of industrial effort. In future, manned military aircraft would be only a small proportion of the effort. The rest would be in missiles, civil aeronautics and space activities. In all of these they would be working increasingly competitively internationally and particularly with America and Russia. To make real impact their technology must be the highest possible. There was no doubt that the two foundation stones on which everything else had to rest were firstly, sound basic technical education and secondly, first-class research effort. At Cambridge, and 40 miles away at Cranfield, both those aims were being pursued. He could not over-emphasise the importance of these two subjects. The Society was closely concerned in both education and research and, therefore, it was an especial pleasure to introduce Professor Murphy.

Since October 1955 Professor Murphy had been Principal of the College of Aeronautics. Graduating from Manchester University in 1920 with First Class Honours in Chemistry, he had first done some research at University College, Swansea, before going to the National Physical Laboratory Metallurgy Department. In 1931, he had joined J. Stone and Company Ltd. as Chief Metallurgist and spent some years in Industry as a Director of that company and its associates. In 1950 he became Professor of Industrial Metallurgy at Birmingham University and, three years later, Director of the Departments of Physical and Industrial Metallurgy, a post he held until his appointment in 1955 as Principal of the College of Aeronautics. Professor Murphy had been President of the Institute of Metals and of the Institution of Metallurgists.

ALTHOUGH the circumstances of the foundation of the College of Aeronautics in 1945 may now be assumed to be fairly well known, it may be useful to recall what the Fedden Report of 1944 had to say about the place of research in the College of Aeronautics for which the Fedden Committee planned. The relevant parts of the Summary of Recommendations of the Report read as follows:—

> "*i.* The primary purpose of the College should be to provide a high grade engineering, technical and scientific training in aeronautics to fit students for leadership in the aircraft industry, civil aviation, the Services, education and research.
>
> *iv.* The instruction should be at postgraduate level or its equivalent, research should be undertaken by staff and selected students, and attention should be paid to the technology as well as the science of aeronautics."

In the body of the Report several paragraphs are devoted to "The Place of Research," and these are worth quoting 15 years after they were written:

> "The place of research in the College will influence its character and deserves some definition. The Aeronautical Research Committee regard as an important function of the College the introduction of selected students to research methods and participation in research and they thought it desirable that some of the staff should engage in research, primarily to maintain their own freshness and vigour. We endorse both of these recommendations. While the first duty of the staff must be to teach,

participation in research is essential if they are to discharge this duty effectively."

This extract from the Fedden Report can be accepted today as a fair statement of the view we take on the place of research in our College.

The people directly engaged in research are the academic staff, Research Fellows, graduate research assistants and students in the second year of the Diploma Course. The establishment makes provision for three Senior and six Junior Fellowships and another Research Fellowship is endowed by the English Electric Co. Ltd. Research assistants are generally working, under the supervision of a senior member of staff, on researches supported through the medium of contracts by outside bodies, which may be Government departments or other concerns, within or outside the Aircraft Industry.

The physical resources available for research will be described in the course of the accounts which follow relating to the activities of the different departments. Because the departments do not have to undertake any appreciable amount of elementary laboratory demonstration, there is not the sharp distinction, which would otherwise be inevitable, between the equipment used in practical instruction and that intended primarily for research.

The intensity of the research effort varies among the departments. This is a consequence of several factors, such as the nature of the subject, the interests and inclinations of the Heads of Departments and their staffs, but probably the most weighty influence is connected with the history of the individual departments. During the time when an important new teaching development is being planned and brought into operation it is inescapable that the energies and time of the staff concerned tend to be diverted at least temporarily from research.

Just as the greatest freedom possible is given to the Head of each Department in the teaching for which he and his staff are responsible, so in research it is for him to decide the volume and general direction of the work undertaken in his department. Collaboration between departments in research is natural and common.

The main portion of this paper consists of contributions from the eight teaching departments and the Library. No attempt has been made to render them into a uniform style or mode of treatment: it is hoped that this method of presentation will convey a sense of that variation in approach and outlook on research which may be regarded as a sign of health in an academic institution.

The most common medium for publications of the results of researches at Cranfield is the series of "College of Aeronautics Reports." Up to the present time 123 of these have appeared. The normal distribution is 280 copies. "C. o. A. Reports" are well known in aeronautical engineering circles: they are regularly noted and reviewed in the Journal of the Royal Aeronautical Society, Applied Mechanics Reviews, Mathematics Reviews and the technical engineering journals. An increasing amount of matter arising from the research at Cranfield is of interest to those outside aeronautical circles: this applies particularly to work in the Departments of Economics and Production, Electrical Engineering and Materials. In these cases more effective dissemination and discussion of the results might be achieved by communicating them in the first instance to the appropriate learned societies, with

FIGURE 1. Aerial view of the College.

eventual reproduction also in the College of Aeronautics Reports series. Attention would naturally have to be given to certain aspects of copyright.

The results of investigations of less importance are published as "College of Aeronautics Notes." The number of these published to date is 99. Students' Research Theses are submitted in uniform typescript and retained in the College Library, where they may be consulted by appointment.

Department of Aerodynamics

INTRODUCTION

The research work of the Department of Aerodynamics over the past few years has covered a wide field of problems relating to hovering flight, vertical and horizontal landing and take-off, subsonic, transonic and supersonic flight and more recently to flight at hypersonic speeds.

On the experimental side the Department has facilities for testing over most of the speed range up to supersonic speeds and new hypersonic equipment is in the process of being installed. The 9 in. × 9 in. supersonic tunnel is now fitted with a two-stage centrifugal compressor which enables the tunnel to operate up to a Mach number of 3. The tunnel is now complete with self-balancing potentiometers for force and moment measurement. The 8 ft. × 6 ft. general purpose low speed tunnel has been in operation for nearly three years. This tunnel has a top speed of about 240 ft./sec. (with screens). Its speed can be altered by varying the pitch of the fan blades manually, and an automatic blade pitch control will shortly be completed. The tunnel has a 6-component electro-mechanical balance manually operated, although it is planned to modify this to read-out automatically.

These two large tunnels are supplemented on the high speed side by a 6 in. × 4 in. intermittent blow-down supersonic tunnel, a 2·5 in. × 2·5 in. intermittent vacuum supersonic tunnel and a 2 in. × 2 in. induction supersonic tunnel, and on the low speed side by an 18 in. × 12 in. low turbulence wind tunnel with 6 screens and a contraction ratio of 50/1, a 3·5 ft. diameter open jet tunnel, a 3·3 ft. elliptical twin open jet tunnel, a 3 ft. × 3 ft. straight-through tunnel and an 18 in. × 12 in. straight-through tunnel, together with miscellaneous demonstration tunnels and smoke tunnels. The Department also has a 7 in. × 5 in. high speed tunnel operating with Freon 12 as the working medium in place of air. It is installing a high pressure shock tube of 2 in. diameter, and a 3 in. diameter helium tunnel for tests at hypersonic speeds. In addition the Department has a small hydraulics laboratory in which there is a hydraulic analogy channel for testing towed models simulating the transonic speed range, and a potential flow electrolytic tank for solving two-dimensional and axisymmetrical potential flow problems in fluid mechanics.

JET NOISE (Refs. 1–5, T1)*

The pioneering work on the noise from jets has continued in both the experimental and theoretical fields. The early experimental work which led to the toothed and corrugated nozzle as a flight noise reducing nozzle is being continued with promising results, as are developments of the wide angle diffuser type of ground muffler. The programme has been extended to include boundary layer noise, a field which is causing concern in the design of missiles and supersonic aircraft. This has led to the development of recording equipment using magnetic tape with a response up to 100 kc., and turbulence equipment for making space-time velocity and pressure correlations. These are required for the evaluation of the strength of the noise sources in jets and boundary layers, as well as for providing basic information on the structure of turbulent shear layers. The Lighthill theory of jet noise has been extended so that with the help of only a few assumptions the strength of the noise sources in a subsonic and low supersonic jet can be evaluated and thereby the directivity pattern of the noise in the radiation field can be obtained. The problem of noise from supersonic aircraft, including the "supersonic bang" problem, which today is seen as a problem of the first magnitude in connection with supersonic transport, has been investigated. Both the theoretical work and experiments in the hydraulic analogy channel made useful contributions in this field.

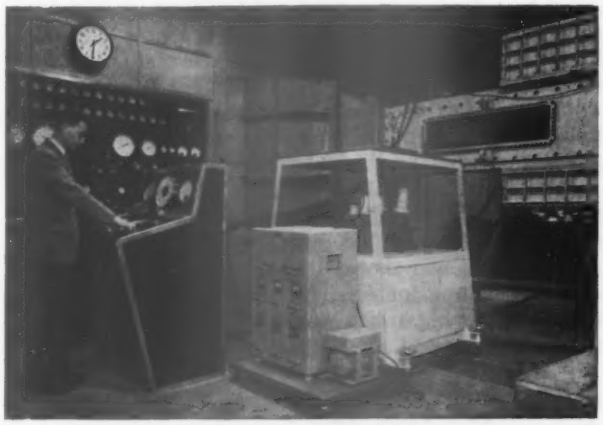

FIGURE 2. 9 in. supersonic wind tunnel.

INTERFERENCE AT SUPERSONIC SPEEDS (Refs. 6–11, T2–T3)

Experiments at a Mach number of 2 on the interference characteristics of low aspect ratio wings on cylindrical bodies, which materially helped in the understanding of the non-linear pitch-yaw coupling effects on guided missiles, were conducted in the 9 in. × 9 in. supersonic tunnel (Fig. 2). This tunnel is now being used for research on jet-body interference and base drag at supersonic speeds and extends earlier work done in the 3 ft. × 3 ft. wind tunnel at subsonic speeds. In addition, lift and drag characteristics of missile head shapes have been measured experimentally in the 2·5 in. × 2·5 in. supersonic tunnel at various supersonic speeds between Mach numbers of 1·8 and 3·3 and the results have been compared with slender body theory. This

*References are listed at the end of the paper. The prefix "T" indicates a reference to a Student's Thesis.

work is associated with the aerodynamic characteristics of shells and missiles.

USE OF FREON IN A WIND TUNNEL (Ref. 12)

Experiments on the characteristics of wings at high subsonic speeds in the Freon 12 wind tunnel showed that the effect of the different ratio of specific heats from that in air could be allowed for by the employment of the transonic similarity rules in reducing the results. This work confirmed the earlier work of von Doenhoff in the U.S.A. and showed the advantage, as to tunnel size and power for a given test Mach number and Reynolds number, which would be gained by the use of Freon 12 instead of air.

SLENDER WINGS AND BODIES AT LOW SUBSONIC SPEEDS (Refs. 13–22, T4–T7)

The characteristics of slender wings and bodies at low speeds have been the subject of much of the recent research work in the low speed tunnels. The loading and flow over a sharp-edged delta wing of 40° apex angle have been obtained experimentally, and a theoretical model has been explored in the potential flow tank. The longitudinal and lateral oscillatory characteristics of sharp-edged fins and wings have also been obtained. The effects of cambering the head and tail of a circular fuselage, pointed at both ends, have been measured in order to determine the camber line shape associated with the maximum pitching moment for no drag increase.

JET WINGS AND JET LIFT (Refs. T8 and T9)

The use of spanwise jet blowing on slender wings as a means of control and of increasing the maximum lift has been demonstrated in tests on a swept wing and a body of revolution, and is the subject of work on a cropped delta wing. The aerodynamic characteristics of circular wings near the ground ("hovercraft" principle) have also been investigated with a view to the determination of the flow structure. In the field of vertical take-off the characteristics of a jet normal to a stream have been obtained.

POWERED-LIFT SYSTEMS (Refs. 23–25, T10)

Theoretical work is in progress on the problem of the jet flap with ground effect. The problem of flow separation has been demonstrated by experiments on a circular cylinder with a jet for which the inviscid theoretical solution was obtained from tests in the potential flow tank.

Preliminary theoretical work has been done on the application of the jet flap principle to helicopters, indicating advantages that warrant further development of such arrangements. A similar study has been made of convertiplane configurations in which the helicopter feature of long hoverability is combined with the aeroplane feature of high forward speed.

The inherent instability of a conventional helicopter when hovering has been studied mathematically and it has been shown how automatic stabilisation can be effected by a simple mechanical system without the assistance of electronic devices.

BLADE FLUTTER (Refs. 26–29, T11)

Previous work on the flexure-torsion flutter of aerofoils in cascade has been extended to the case of aerofoils with incidence over a wide range of stagger. This work, although not of direct interest to the design of compressor and turbine blades, at least draws attention to some of the major design problems.

PROJECT ACTIVITIES (Ref. 30)

Recent project studies on different types of aircraft include a canard layout, at a Mach number of 3, photographic reconnaissance aircraft, a Mach number 1·5 low level bomber and an "ogee" wing, Mach number 2, supersonic air liner. Low speed wind tunnel tests have been conducted to explore the longitudinal and lateral characteristics of these projects. The non-linear lift effects have proved most enlightening.

MAN POWERED FLIGHT (Ref. 31)

The challenge of the man powered aeroplane was taken up a few years ago and tests were made on the wing characteristics, longitudinal and lateral characteristics, as well as the power output from cyclists. The problem of power storage by stretched rubber has been investigated. The results of these various tests show without doubt that a man with suitable skill is capable of flying by his own effort.

HELIUM HYPERSONIC WIND TUNNEL AND SHOCK TUBE (Ref. 32)

The design and installation of a shock tube (Fig. 3) and a pilot hypersonic tunnel using helium as the working medium have been undertaken, as well as the

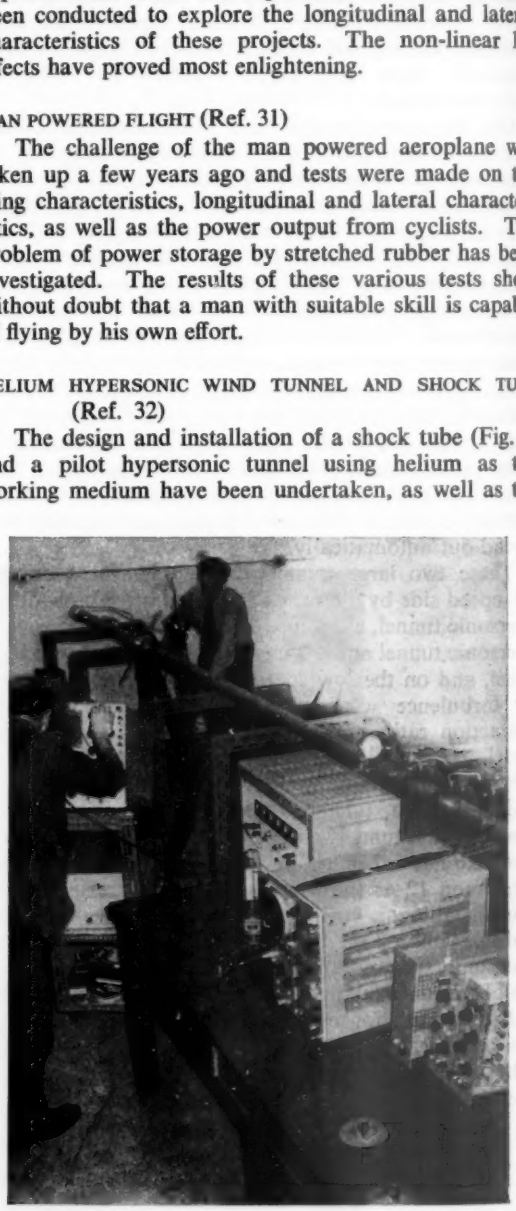

FIGURE 3. Shock tube.

development of a new short-duration high light intensity spark source, a Schlieren interferometer using polarised light and a Mach-Zehnder interferometer. The design of axisymmetric nozzles for a helium tunnel with boundary layer corrections has been programmed on the Oxford "Mercury" digital computer.

Theoretical work in the field of real gas effects associated with the high temperatures present in hypersonic flows has been developed, covering problems of real gas effects in boundary layers, expansion round a corner, and sound absorption and dispersion. Experimental studies of these problems are being conducted in the shock tube.

HEAT TRANSFER IN DISSOCIATED GASES (Refs. 33–34)

This problem arises during hypersonic flight, where the gas temperatures achieved are sufficient to dissociate most of the atmospheric oxygen molecules, some of the nitrogen, and also to cause some degree of ionisation.

An early Couette flow study of a pre-dissociated diatomic gas (oxygen, for example) showed the significance of mass diffusion rates, since it is by these means that the chemical energy is transported through the gas, and also indicated the importance of the region in which such chemical energy is liberated. Thus the final heat transfer rate to the walls of a body immersed in a dissociated gas can depend quite critically on the efficiency of the wall as a catalyst for the atomic recombination reaction. Work on the problem of heat transfer to a flat plate in which all recombination occurs on the surface has been undertaken, and the results have been confirmed by papers published recently in the U.S.A. Experimental work on heat transfer in dissociated gases will begin shortly in the shock tube.

ABLATION (Ref. T12)

The ablation of surface material into the boundary layer is another of the phenomena which may be encountered in hypersonic flight. The reductions in heat transfer rate to the interior of a missile which can be achieved by, for instance, allowing the surface material to vaporise can be significant, the process acting as a kind of self-regulating gas injection system. It is not immediately obvious whether a surface material of high or low latent heat of vaporisation is better in these circumstances, since, with a low value more mass is injected into the boundary per unit time, while with a high latent heat more energy is absorbed in vaporising the material and less will penetrate to the inner regions of the body. A simple Couette flow study shows that as high a value as possible is best. The theoretical work on ablation and injection is continuing with further Couette flow studies of more complex gas mixtures and an examination of vaporisation from the surface of a flat plate. Some preliminary experimental work on the melting of bodies at high temperatures has been begun using models made from eutectic lead-tin alloy at a Mach number of 2.

GAS FLOWS WITH CHEMICAL REACTIONS (Refs. 35–37)

The general study of inviscid gas flows in which reactions occur is of importance in a number of fields. Recent work has shown the relationships existing between the speeds of sound in gases for which chemical reactions are either very fast or very slow and the velocity occurring at the throat of a Laval nozzle running under choking conditions. It is a measure of the extra complications introduced by the chemistry that all of these speeds will in general be different.

The flow of a dissociated gas has been examined using a linear theory which has been shown to agree well with exact characteristics computations. This theory has pointed the way to a possible shock tube experiment to measure reaction rates in pure gases and further work is proceeding on more complicated gas mixtures.

The correct design of nozzles for shock tunnel facilities is a further important problem in this field. This is being examined using characteristics theory.

MAGNETOGASDYNAMICS (Ref. T13)

Theoretical work on the interaction between magnetic and electric fields and ionised, conducting gases has been started, and an extension of some previous Canadian work has been made which is relevant to possible experiments that can be conducted in an annular shock tube. This is concerned with the effects of continuum radiation from the hot gas and perturbations induced in the applied magnetic field on the conditions necessary for observable interactions to appear.

Present work includes a theoretical and experimental investigation of the Kolb or T-tube, in which shock Mach numbers of 400 and exceptionally high plasma temperatures can be achieved.

HEAT CONDUCTION (Ref. 38)

The advent of short-duration test facilities has focused attention on transient phenomena in gases, an example being the sudden contact between a hot gas and a cold wall. In these circumstances it is strictly necessary to include the effects of gas compressibility in treating one-dimensional unsteady heat conduction problems in gases. A theoretical treatment valid for un-ionised monatomic gases has indicated the nature of the pressure and temperature perturbations resulting from sudden contact between a semi-infinite cold solid and a semi-infinite hot gas. Further work includes the effects of chemical reactions and molecular structure and shock tube experiments designed to check the theory.

FUTURE RESEARCH IN HYPERSONIC AERODYNAMICS

The new shock tube is designed to operate at maximum driver pressures of 1,000 atmospheres. It will be fitted with a convergent-divergent nozzle and 12 in. diameter working section to produce Mach numbers of about 15 with maximum stagnation temperatures of 8,000°K. Several research programmes are planned and will be concerned initially with the physical properties of dissociated gases with reference to their aerodynamic effects.

At present, the variation of temperature with time at the interface of a hot gas placed suddenly in contact with a cold wall is being investigated. The surface temperature is measured by means of a thin-film resistance thermometer at the closed end of the low pressure section of the shock tube. A shock wave is reflected from this end and consequently hot gas is placed in contact with the wall. This experimental work is being done to check theoretical predictions.

The helium hypersonic tunnel mentioned earlier will operate in the Mach number range 5 to 25 with a stagnation temperature of about 300°K, and will have a running time of 30 sec. The research programme so far planned will include the study of shock wave boundary layer interaction at hypersonic speeds.

In addition to hypersonic research, experimental apparatus for studying magnetogasdynamic effects is being built up. At present a magnetogasdynamic shock tube, known more generally as a Kolb tube, is being run to gain some insight into the fundamentals of magnetogasdynamics. A spark discharge is produced in a gas at low pressure and the interaction of the plasma with a suitable magnetic field causes a shock wave to propagate along a glass tube. Mach numbers of 50 in air have so far been achieved and at present the capacitive storage is being increased to 2,000 joules so that stronger shocks can be generated.

Department of Aircraft Design

INTRODUCTION

Research in the Department of Aircraft Design is carried on by members of the teaching and research staff, as well as by students, under the direction of the staff, working on their research or project theses. The wide range of subjects covered includes design studies of aeroplanes as well as special investigations into engineering and scientific problems of practical interest. Emphasis is placed upon the unity of theory, experiment and design practice.

FIGURE 4. Mach 2 fighter (1953 project).

The purpose of much of the research is instructional. The aim is to teach students the art of research by giving them the opportunity, under the general direction of a member of staff, of investigating an individual problem for themselves. As might be expected, this exercise does not always produce, in the time available, complete and satisfactory answers to the problems posed. However, attempts by succeeding generations of students, combined with individual work by staff members often yield results of value.

DESIGN STUDIES OF AEROPLANES

The object of research in this field is to gain knowledge of what form the best design of aeroplane should take so that the resulting flying machine may meet a certain specification or perform a certain rôle. The solution to any problem of this kind should specify the aerodynamic configuration, the power plant, the materials and type of construction and the nature of the auxiliary systems. It must be completely practical both in relation to manufacture and operation and as far as possible must be demonstrated to be an optimum in relation to all-up weight, initial and running cost and operational efficiency.

A preliminary study of one, or sometimes two, aircraft or guided missiles is carried out each year by staff in the department. There is close co-operation with the Aerodynamics Department, and much advice on special problems is obtained from other departments of the College. A general arrangement drawing and a weight

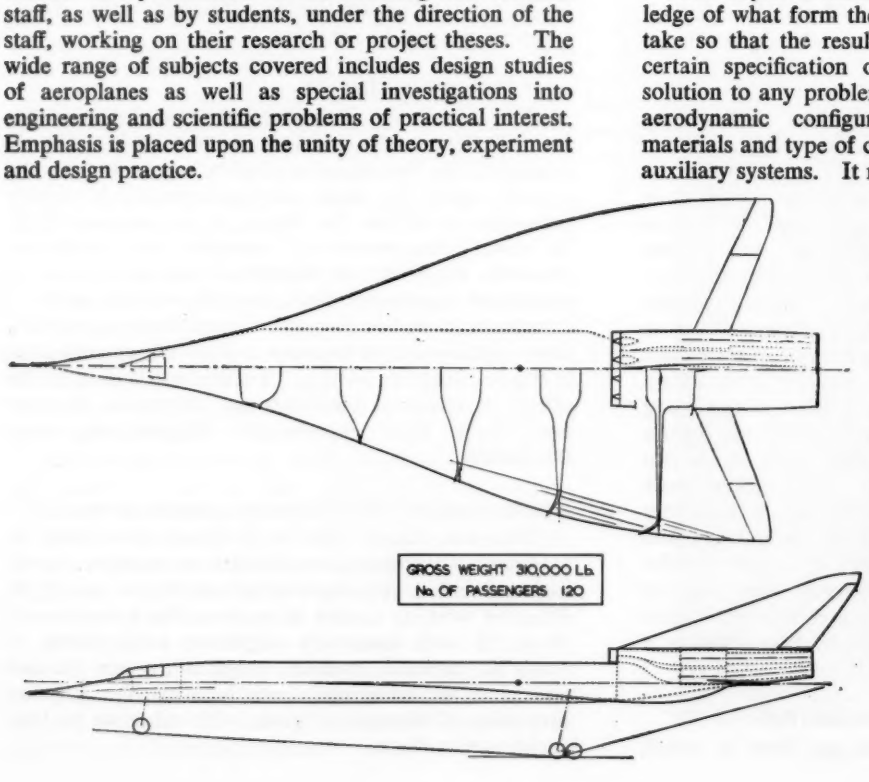

FIGURE 5. Supersonic air liner (1960 project).

estimate are produced, and the design work is then handed over to a team of second year Diploma students, each of whom carries out the detail design of a component, and submits his results as a thesis in part fulfilment of the requirements for the Diploma of the College. The students are expected to design their components to standards of adequate strength and stiffness, to minimise the weight and to ensure the practicability of constructional methods and functions. They must realise in hardware the general concept of the design.

One of the more recent projects is shown in Fig. 4. A glimpse into the future is provided in Fig. 5, which shows a supersonic transport under consideration now for this year's design study. These designs sometimes show an interesting resemblance to the solutions derived by the aircraft firms. This coincidence of thinking is interpreted as an indication that the project work in the Department of Aircraft Design is proceeding along sound lines. The problems involved in the incorporation of the tail-first configuration, the installation of engines in the rear of the fuselage, variable intakes, steel sandwich construction and integral skins of high tensile steel, were tackled as serious design projects in the department before their application by the Industry was generally known.

The purpose of project design studies in a teaching establishment is two-fold. In the first place they provide up-to-date material for students' instruction of a kind which could not be obtained from published information, but which is certainly necessary to give adequate training to those about to enter the Aircraft Industry in responsible positions. In the second place they serve to keep the staff of the department closely in touch with the latest problems of aeronautical practice. Reading the literature and talking to engineers in the Industry is valuable, but actually doing the job oneself is the most rewarding of all.

LABORATORY FACILITIES

The majority of the special research investigations carried out in the department fall under the headings of Applied Mechanics or, in particular, Structures. Experimental work in these fields requires equipment which will supply a realistic environment for the test specimens, as well as measuring equipment to record the effects produced.

The first requirement is to impose forces and constraints. The laboratories are equipped with some eight standard testing machines with load ranges up to 70 tons in tension and 150 tons in compression and include a 35 ton Losenhausen Fatigue machine. There are also a number of loading frames, the most recent of which is a "cruciform rig" (*see* Fig. 6) with four testing bays mounted on a central block of reinforced concrete in the form of a 10 ft. cube. Six electromagnetic excitors are available for vibration testing, and elastic mountings for dynamic models of aeroplanes are a standard facility. The special problems of drop testing of undercarriages are catered for by a swinging link machine, mounted above a moving 12 ft. diameter flywheel, which

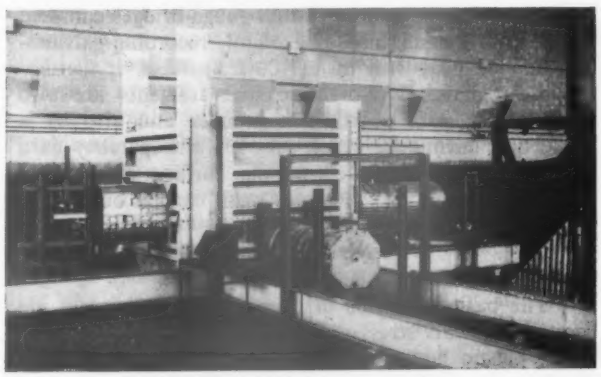

FIGURE 6. Cruciform test rig.

enables the correct relative velocity between wheel and ground to be achieved, and so permits drag and side loads on the wheel to be realistically represented. This unique installation is shown in Fig. 7.

The special problems associated with the simulation of kinetic heating effects in aeroplane structures have led to the installation of many small heating units and controllers, which have been used in student thesis work. A larger facility with a capacity of one megawatt is in the course of construction.

The laboratories are well equipped with measuring

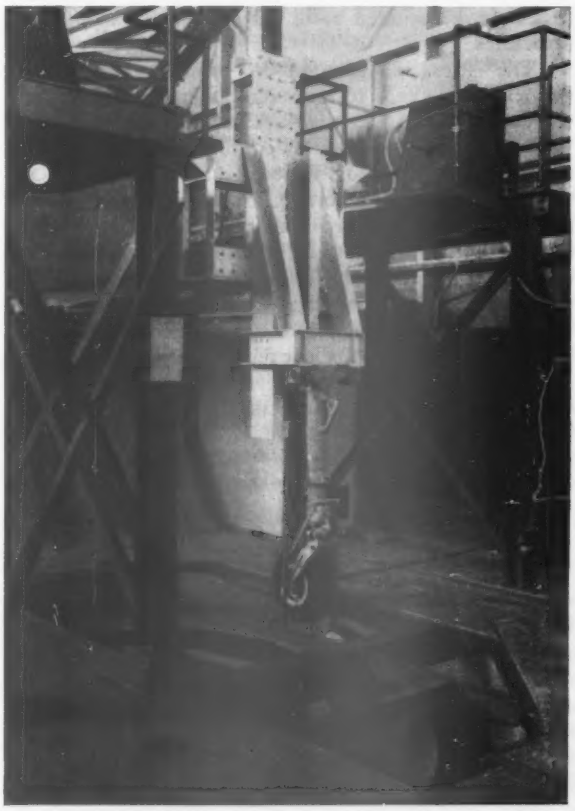

FIGURE 7. Drop test rig.

and recording apparatus. Strain gauge bridges can deal with some 450 static readings, while recording galvanometers can deal with up to 100 transducer or thermocouple signals. Photo-elastic measurements are also made, both in the orthodox manner and also by a reflection technique, which uses the transparency as a strain indicator attached to the surface of a metal specimen under test. Pioneer work carried out in this last field is described in Ref. 39.

STRUCTURES RESEARCH

The basic problems of the theory of structures are concerned with stress distribution, deformation, buckling, plastic flow including creep, and fracture under both static and fatigue conditions. The development of mathematical theories for the prediction of these phenomena and their verification by experiment characterise most of the departmental research and the students' thesis investigations. Problems of optimum design for both general and special structural forms are also receiving attention. The use of electronic digital computers is a growing feature of many of the investigations.

The problems presented by delta and other low aspect ratio wings have been the subject of many studies. The use of oblique Cartesian co-ordinates introduced in Ref. 40 and applied to multi-web structures in Ref. 41 has been the basis for the theoretical side of much of this work, (*see*, for example, Refs. 42 and 43). Specimens tested have included solid plates as well as built up structures[T14-T17].

The stress distribution in pressure cabins with particular reference to reinforcing member stiffness and to cut-outs has been a special feature[44, 45]. The theoretical analysis of stress concentration at plain and reinforced cut-outs of various shapes, including the square with rounded corners, by the complex variable methods of Muskhelishvili has been successfully carried out. Both conformal transformation and the direct use of integral equations has been considered[T18-T20]. The problems which arise when spherical and cylindrical shells are joined together have been studied[46]. This has an application to nuclear reactor design.

Much attention has been given to problems associated with thermal effects. Experimental checks have been made on the temperature distribution in multi-web boxes and the thermal resistance of joints has been studied[T21, T22]. The thermal stress distributions in finite length multi-web boxes and in stiffened cylindrical shells have been investigated[47, 48], and measurements have been made of the loss of stiffness of plates heated at their edges. A study of incremental collapse, as predicted by E. W. Parkes, is in hand, but experimental difficulties associated with the production of rapid cooling have been experienced. Basic theoretical work has also been carried out in the field of thermo-elasticity[49].

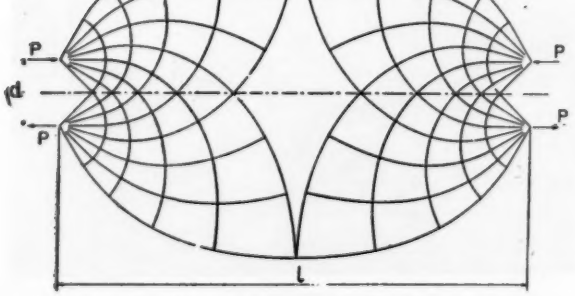

FIGURE 8. Optimum structure for pure bending moment.

Investigations into the buckling of stressed skin and sandwich construction have been common over the years among the research thesis subjects[T23, T24]. Recent studies have been concerned with the effects of plasticity on the buckling of plates in shear[50, T25]. These have confirmed the fact that the physically correct "flow theory" over-estimates buckling stresses, while the "incremental theory" is in better agreement with experiment. Some theoretical work has also been carried out in the field of creep buckling and experimental work is in hand[T26].

Studies are being made of the stress distribution in problems of contained plasticity. It is expected that difficulties of numerical analysis will be overcome by the use of an electronic digital computer. The accuracy of creep laws under conditions of varying stress is being investigated. The results should have an important bearing on the problems of creep buckling.

Extensive experimental investigations have been made into the fatigue strength of detail parts and into the propagation of cracks in sheet under steady and fatigue conditions. Theoretical work on cumulative damage has had some measure of success, but attempts to find regularities in crack propagation rates under varying fatigue stress levels have been abortive[T27-T29].

Experimental investigations have been made into the performance of bearings under high pressure and at elevated temperatures with a view to assessing their functioning for control surfaces in fighter wings[51].

Theoretical investigations have been carried out in the manner of Michell into the optimum layout of framed and plate structures. Mathematical developments have been reported in Ref. 52 and applications, using the analogy with the slip line field in two-dimensional plastic flow, have been made to the design of cantilevers under tip load and to beams carrying a pure bending moment. The lightest and stiffest known structure for the transmission of a pure bending moment is shown in Fig. 8. Optimum studies have also been made of particular constructional forms. Multi-web boxes are considered in Refs. 53 and 54, and pressurised cylinders in Ref. 55.

VIBRATION RESEARCH

Vibration analysis plays a vital part in aircraft design. Aeroplanes are often so flexible that vibrations induced by suddenly applied loads, for example gusts or landing reactions, play a significant part in their stress analysis. Aeroelastic instability or flutter is often the

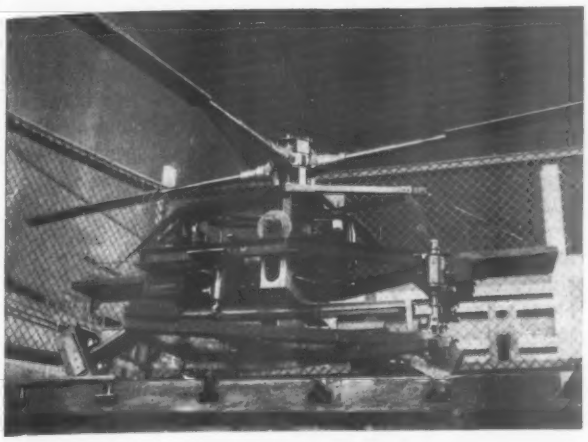

FIGURE 9. Helicopter test rig.

main "design case" for the structural design of a wing or similar surface. The flexibility of the "narrow delta" configuration has a decisive influence on its longitudinal stability. A knowledge of the modes of vibration is thus a necessary preliminary to satisfactory design.

The design of vibration models of aeroplanes, as a means for the prediction of normal modes in the early stages of design, has always been a feature of the Department's work[T30]. Recent studies have made use of such models, equipped with undercarriages, to study the loads experienced by outriggers during landing and design information thus obtained was used on one of the aircraft projects[T31].

Studies have also been made of full scale resonance test analysis. The use of multi-point excitation has been investigated and the use of the vector response plotting technique, applied to critical cases with near coincident frequencies, has been examined[T32].

Investigations have been made into methods for producing very light-weight models for flutter testing with a view to studying tail flutter. Panel flutter and divergence have been studied theoretically[56-58] and work is now in hand to test the theory by wind tunnel experiments.

The subject of helicopter "ground resonance," which is a self-excited vibration involving coupling between movement of the blades about their drag hinges and the motions of the rigid aeroplane upon its undercarriage system, has been investigated theoretically and experimentally[T33-T36]. Considerable success has been achieved in predicting full scale phenomena by means of mechanical models. Some of the work is described in Ref. 59, and a picture of one of the models is shown in Fig. 9. The drag hinge dampers, which play a critical part in this phenomena, can be seen as well as the springs and dampers representing the suspension system of the aeroplane. Torsional vibration of helicopter transmission systems has also been studied[T37].

FIGURE 10. Gear test rig.

Department of Aircraft Propulsion

The research interests of this Department cover a wide field, since propulsion is achieved by a large variety of devices ranging from piston engines through gas turbines and ram-jets to rockets of various types. The rocket field will expand beyond conventional chemical rockets to thermal rockets, using hot hydrogen as the ejected fluid, and electrical rockets in which the ejected fluid is either a plasma or a jet of ionised particles (the so-called "ion rocket"). All the various propulsion devices throw up mechanical, chemical and fluid dynamical problems, and research in the Department has, therefore, been distributed over a wide range of fundamental subjects.

The equipment of the Department corresponds to the mechanical, thermodynamic, chemical and fluid dynamical fields mentioned, besides, of course, the normal teaching equipment of which actual engine test equipment forms a large and important part. Mechanical research is, for the most part, concentrated in two laboratories, the Mechanisms Laboratory and the Vibration Laboratory. Fluid dynamic research is spread over various laboratories, including the Hydraulics Laboratory, and chemical research is concentrated in the Fuels Laboratory. Equipment is further sub-divided into "quiet" and "noisy," the latter being located about half a mile from the centre of the College. In this "test area" is located the main departmental air supply, comprising four blowers, each driven by 500 h.p. motors. The air from these blowers is fed to a number of different test houses which were converted from the Royal Air Force bomb storage houses and have proved to be extremely useful laboratories. Twelve exist, each 26 ft. square and 14 ft. high.

MECHANICAL RESEARCH

Research in the mechanical field, over the past year or two, has concentrated on three main items.

The first of these, research into the dynamic loading of gear teeth, has been carried out under contract. Spur gears of about 9 in. diameter are run in a power circulating rig (Fig. 10) at speeds up to about 10,000 r.p.m. Extreme care is taken to align the test gears accurately. A particular tooth on one of the test gears is strain-gauged (Fig. 11), a piezo electric-type gauge of high sensitivity being used, and the signal taken out

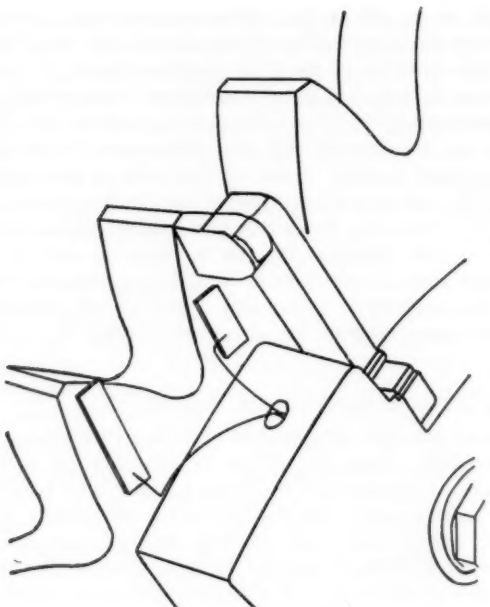

FIGURE 11. Test gear with piezo-electric strain gauge attached to side of tooth.

through slip rings. Recording of the signal from equipment of this type presents a variety of difficulties, particularly in respect of achieving economy of photographic material. Rather than use continuous film recording, a trigger device is adopted which permits recording to be restricted to the period during which the test tooth is in mesh. Maximum power transmission through the test gear is about 1,000 h.p., while the input power is lower by a factor of about 20. The gear teeth pass through quite sharply defined resonances. The maximum stress so far indicated on the gear wheels tested has been about $1\frac{1}{2}$ times the "static stress," *i.e.* about $1\frac{1}{2}$ times the stress obtained when the gears are rotating slowly enough for dynamic loading effects to be absent.

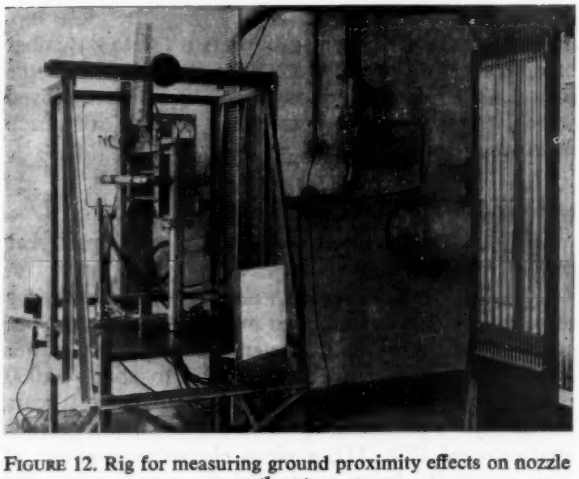

FIGURE 12. Rig for measuring ground proximity effects on nozzle thrust.

Bearing research has been carried out on a bearing rig, and has sought information on the relation between bearing temperature (anti-friction bearings) and oil flow quantities at various bearing loads and speeds, roller bearings of $2\frac{1}{2}$ in. diameter bore used with speeds up to 10,000 r.p.m., and journal loads up to 100 lb. The rig simulates aircraft turbine conditions where low journal loads combined with high temperatures are met. To simulate the latter condition, the shaft is hollow and electrically heated. Thermocouples are attached to both the rotating and the stationary tracks of the bearings.

The third main item of mechanical research of the Department has been the investigation of the whirling of complex rotors. The theoretical approach to this subject is much more feasible nowadays than previously, since the extraction of the latent roots of the matrices which result from the theoretical investigation can now be done in a routine manner on digital computers. The rotor is a steel shaft 21 in. long and $\frac{1}{2}$ in. in diameter, and runs at speeds up to 5,000 r.p.m. It has mounted on it 6 steel discs, each 6 in. diameter, and the dynamic equation of motion, taking into account gyroscopic forces, results in a 24×24 matrix. The rotor is driven by a small air turbine which is, in fact, one of the discs, and is supported on two bearings. The new feature of this rig is that the flexibility of the bearing supports is

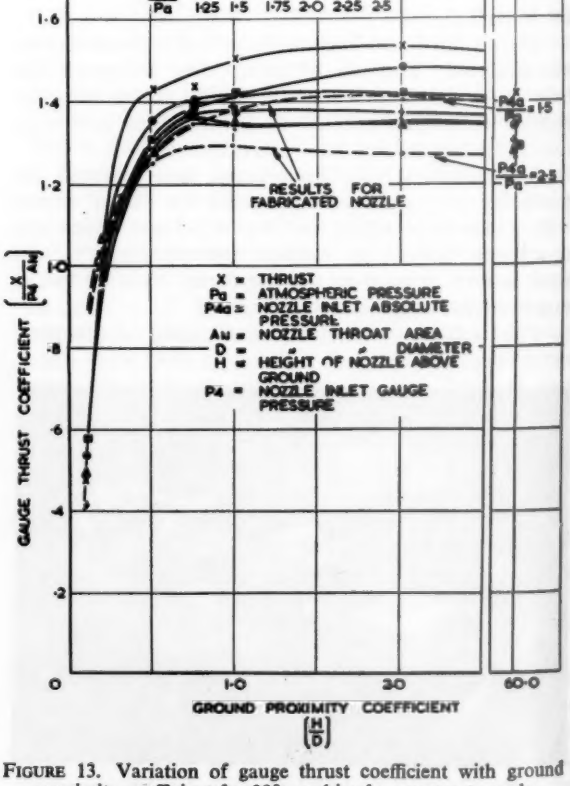

FIGURE 13. Variation of gauge thrust coefficient with ground proximity coefficient for 30° machined convergent nozzle.

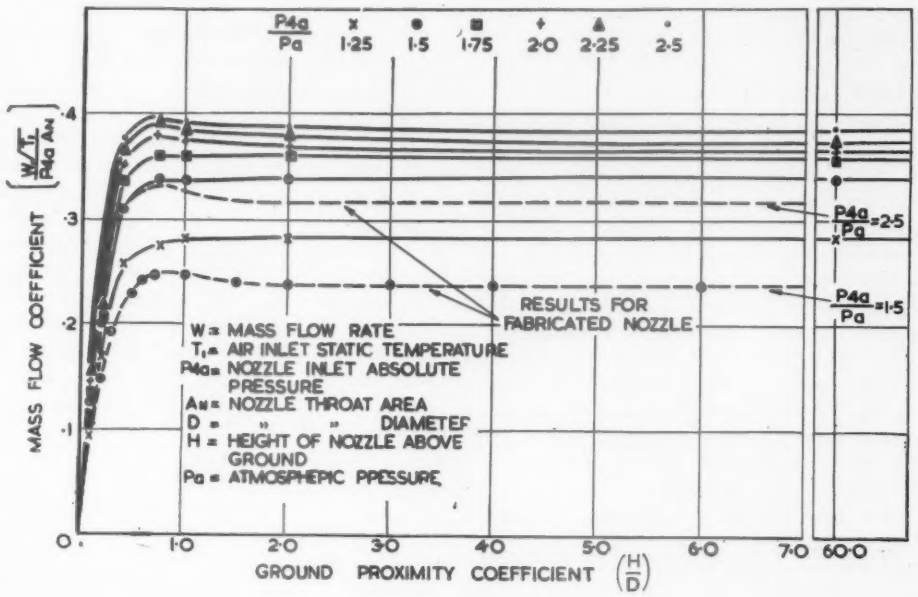

FIGURE 14. Variation of mass flow coefficient with ground proximity coefficient for 30° machined convergent nozzle.

allowed for in the theory; each of the bearings is actually supported by four strong helical springs. By this means it is possible to have anisotropic stiffness in the bearing supports. For instance, the bearing supports can be made more flexible in, say, the horizontal direction than in the vertical direction. This variation of stiffness with direction makes it possible for the phenomenon of "reverse whirl" to occur in the rotor. This effect has actually been observed, deflection of the rotor being detected by electrical pick-ups working on the change of capacity between the rotor and a neighbouring electrode as the rotor is deflected. Display of the signal from such pick-ups permits the detection of the magnitude and direction of a whirling vibration. Further, the various forward and reverse whirls have been watched with a specially developed stroboscope which shows the shaft rotating at 1/64 of its actual speed. It is intended to continue this work up to the whirling of a complete system simulating a complex rotor and a casing. It might be mentioned in passing that there appear still to be some mathematical difficulties in treating a problem of "reverse whirl." However, the critical speeds calculated for this rotor agree quite well with the experimental ones[T38].

AERODYNAMIC RESEARCH

Aerodynamic research is usually carried out in the "test area" where there need be no noise limitations. For the most part air supplies for aerodynamic research come from the blower totalling 2,000 h.p., but small high-power demands are met by a 180 h.p. supply at 8 atmospheres, or by air bottles charged up to 2,000 p.s.i.

An example of the aerodynamic research of the Department is the work on the effect of ground proximity on the thrust produced from an engine producing a downward jet. This subject is of some current interest in view of the advent of vertical take-off and landing aircraft using lifting jets. Small nozzles were arranged to be fed with air up to 8 atmospheres in pressure and were held in a force balance. A photograph of the rig is shown in Fig. 12 and typical results are given in Figs. 13 and 14. It will be noted that for the "30° machined convergent nozzle," when the ground is within half of a nozzle diameter of the end of the nozzle, the thrust begins to fall off appreciably. This is due to suction on the flat end of the nozzle. Results were not carried right down to zero distance from the ground; had they been, the thrust as presented non-dimensionally would have been unity. The difference in results as between the "fabricated nozzle" and the "30° machined convergent nozzle" is due mainly to the fact that the former had a sharp end, whereas the latter had a "flat end" whose outside diameter was 1 in. as compared with the nozzle diameter of ½ in. Thus suction effects were greater on the "machined nozzle." The air flow in the region of the nozzle exit was investigated both by the normal Pitot and static measure-

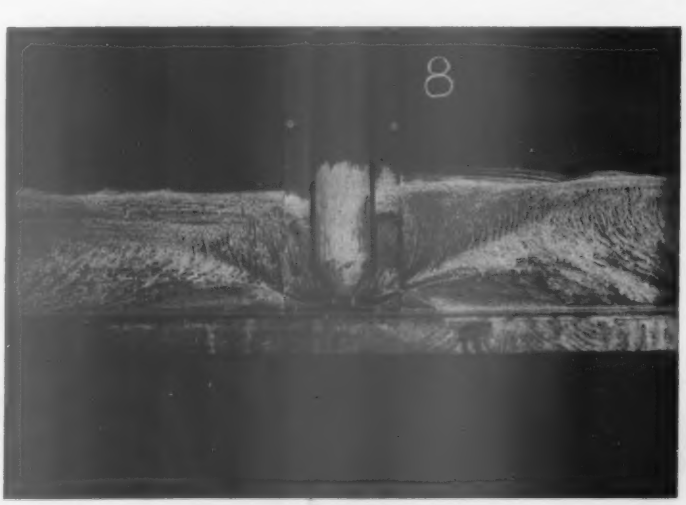

FIGURE 15. Aerodynamic smear patterns near the exit from a nozzle.

ment technique, and by various flow visualisation techniques[T39, T40]. (Fig. 15).

ROCKET RESEARCH

Many fundamental problems in the field of rocket propulsion exist. The severe nature of these problems is shown by the number of large rocket launchings which are unsuccessful. The need for a rocket test bed was felt long ago at Cranfield, and in 1955 a rocket motor test bed to test rockets of up to 3,000 lb. thrust was brought into operation. So far the bed has been operated almost entirely with liquid propellant rockets, mainly a rocket of a type supplied by Napier's of 2,000 lb. thrust. This rocket uses hydrogen peroxide and kerosine as its propellant combination. It is a small rocket, 50 times smaller than liquid oxygen/kerosine motors currently powering some American rockets, and 500 times smaller than some rocket motors currently in development in the U.S.A. Though the Cranfield small rocket is used mainly for teaching purposes, it provides, nevertheless, the possibility of certain research in the field of liquid propellant motors. The motors have given evidence on the effect of combustion chamber length; the reduction in efficiency on making the chamber too short; the effect of varying the quantity of silver-plated gauzes used to decompose the hydrogen peroxide before its reaction with the kerosine; and the effect of deliberately lowering the injector efficiency. It became clear that the results of these investigations would have been more useful had it been possible to measure fluctuating rather than mean combustion pressures. A very useful pressure transducer was produced to measure these fluctuating pressures. The mean pressure on the transducer was backed off by high pressure nitrogen, so that the transducer element was exposed only to the fluctuating part of the pressure. By this means the transducer element, which was a strain tube, could be made more sensitive than was possible had it been required to withstand the whole full steady component of the pressure.

It is extremely difficult to detect the flow pattern of the reacting gases in a rocket combustion chamber. The combination of high pressure, often of the order of 500 p.s.i., and temperature (often of the order of 3,000°C), makes the use of common visualisation and probing techniques impossible. The knowledge of flow patterns is, however, useful background information to the designer, who often considers changes in the injector system with a view to improving combustion efficiency or stability, or to decreasing the heat transfer to the walls of the combustion chamber. A successful method of investigating flow patterns within the combustion chamber, found at Cranfield, was the extension of the aerodynamic smear technique. A diaphragm of tungsten on a meridian plane dividing the combustion chamber into two was coated with a flame-sprayed zirconia (Rokide 2). Not only did this zirconia smear and thus indicate the flow directions, but colour contours on it were found which were thought to indicate contours of composition of reactants within the chamber.

Among other rocket work may be mentioned a theoretical investigation into the problem of high frequency pressure oscillations in solid propellant rocket motors. The investigation indicated that the burning rate of a solid propellant was likely to be very sensitive to high frequency fluctuations of gas pressure within the rocket, the sensitivity increasing as the frequency increased. A theoretical study is being undertaken of rocket engine operation and design to meet a wide range of specifications with minimum vehicle mass. Part of this work examined the problem of landing instruments softly upon the moon[60, 61].

FUEL AND COMBUSTION RESEARCH

The problems of the properties of fuel and their burning have led to a number of research investigations, which can be described under the following headings.

Spontaneous Ignition

An apparatus of the ASTM type, comprising a conical flask held in a bath of molten metal, has been constructed for the determination of spontaneous ignition temperatures of liquid fuels at atmospheric pressure. The conditions of the test are similar to those which would obtain at low altitude in a supersonic

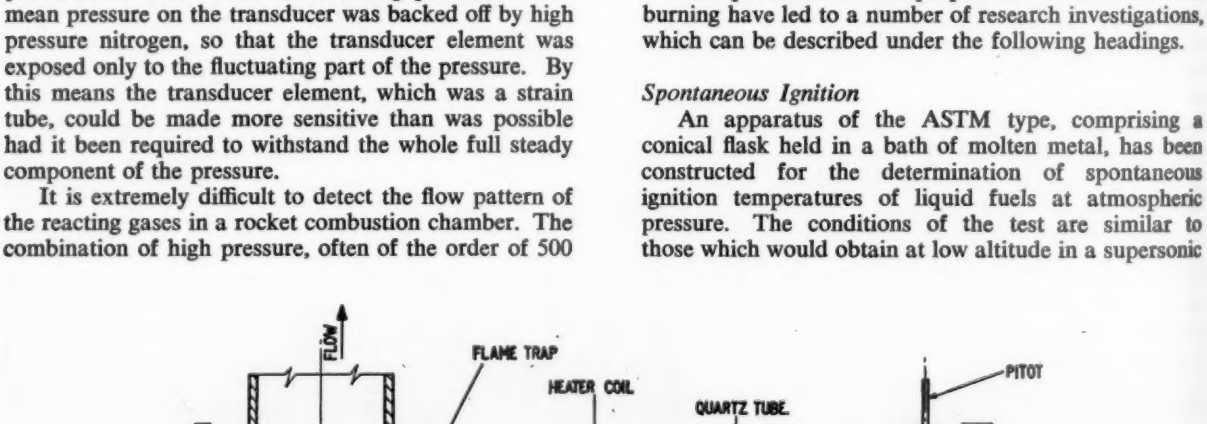

FIGURE 16. Atmospheric surface ignition flow rig. Test section.

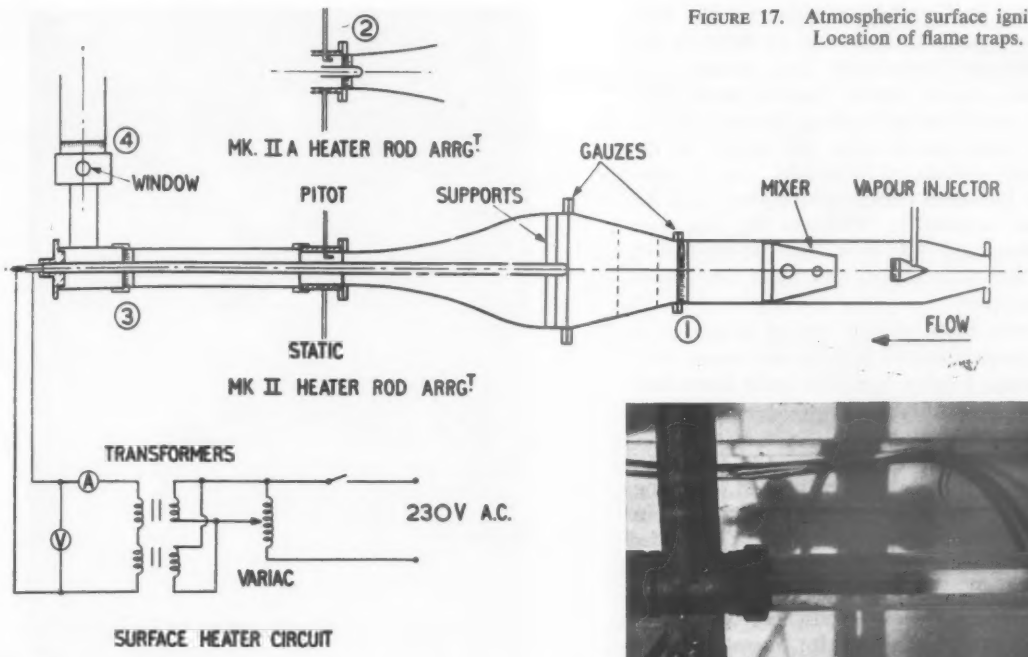

FIGURE 17. Atmospheric surface ignition flow rigs. Location of flame traps.

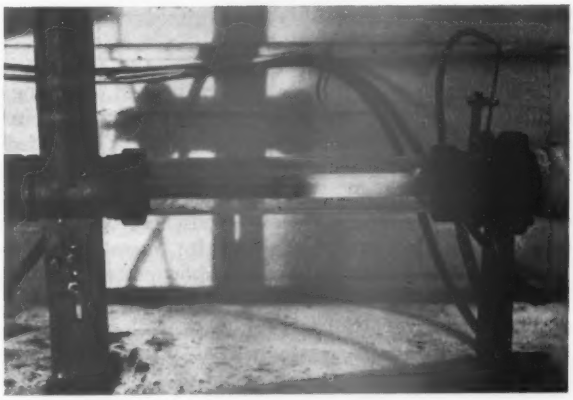

FIGURE 18. Atmospheric surface ignition flow rig. Heater rod at 900°C.

aircraft fuel tank, or near an engine bay in an aircraft mainplane following leakage of fuel. As a routine measure, the relative ignitability of all fuels used in the Department is assessed by means of this test[62]. Work is in hand to improve the accuracy and repeatability of the test.

In spark-ignition piston engines spontaneous ignition is a factor controlling the onset of knock at the end of the combustion process. A particular form of spontaneous ignition, in which the mixture is ignited locally by means of a heated surface, is the factor controlling pre-ignition, which occurs at lower pressure at the beginning of the combustion process. To date, gasolines are rated solely on a knock basis, but the possible development of the pre-ignition problem with increased compression ratio emphasises the importance of pre-ignition research, particularly since fuels behave very differently under these two conditions. Although engine tests are essential eventually, the results are complicated by three superimposed effects. These are the tendency of the fuel to form deposits, the tendency of the deposits to glow, and the tendency to ignition induced by these glowing deposits or by other overheated surfaces. In an attempt to separate these effects, a surface-ignition flow rig has been constructed in the form of a heated cylindrical surface located axially in a transparent cylindrical duct. Ignition takes place within a thermal, as distinct from an aerodynamic, boundary layer, and the results indicate the contact time, based on the free stream velocity, associated with the surface ignition. Certain pure hydrocarbons, of high ignitability, have been tested at atmospheric pressure. Surface temperatures in excess of about 910°C are found necessary to initiate ignition with a "free stream" contact time of 25 sec. or less. It has also been found possible to derive the temperature of the first element of mixture to ignite under these conditions, and hence to compare the results with the more conventional spontaneous ignition data. The rig is also being used to investigate the effects of additives. Acetaldehyde appears to give a slight pre-ignition effect with the fuels tested, whereas water increases the ignition surface temperature. This is of practical interest since water injection is in current use as a method of knock suppression. The present work shows that water injection systems will also suppress pre-ignition. Work on this rig continues, together with the construction of a high pressure rig designed to operate under the conditions at which pre-ignition occurs in an engine, *i.e.* 3 to 5 atmospheres[63] (Figs. 16–18).

Some preliminary work is in hand on pre-ignition in engines. In tests reported in the literature pre-ignition is induced artificially by means of surfaces, either of coiled wires or circular discs, located within the combustion chamber and heated either by the combustion gases themselves or by an external heat source. Results have shown the effects of the major controlling variables and of fuel type, and have raised the following points:—

(*a*) the shape of the heated surfaces, and the local mixture flow, are such that no indication is available of contact time or ignition delay,

(*b*) conflicting results have appeared on the effects of engine speed.

In an attempt to solve problem (*a*), pre-ignition units

have been designed at Cranfield to constrain the flow direction over the heated surface, and so improve the repeatability. Previous experience had shown that normally aspirated engines needed heated pre-ignition units, whereas in supercharged engines the unit needed cooling. These requirements were not found in the normally aspirated engines at Cranfield, and a composite pre-igniter has been designed with provision for both heating and cooling[63]. Problem (*b*) has been investigated further, and it is seen that pre-ignition is first aggravated and then suppressed by a continuous increase in engine speed[64].

Flow tests have been carried out in a nozzle to investigate the possibilities of ignition by means of a strong shock wave. Highly ignitable fuels have been used, but without success[T41, T42].

Flame Stabilisation

Following a suggestion by Professor D. B. Spalding, combustion tests have been conducted with $\frac{3}{8}$ in. diameter rod stabilisers of porous stainless steel fed internally with kerosine at low pressure. Low blow-out velocities and tendencies to carbon deposition led to the design of a stalled cascade of porous aerofoil sections located in a wind tunnel equipped for operation up to 3 atmospheres. Preliminary results show performance to be poor under laminar flow conditions, and little better at high incidence. Subsequent work will include investigations of alternative geometries of greater degrees of bluffness[65, T43].

Special Fuels

The performance of a gaseous hydrogen-oxygen rocket motor has been investigated, over an O_2/H_2 mass ratio of 3·5 to 18 (stoichiometric ratio, 8). A system has been designed to handle these propellants in the liquid phase[T44, T45].

Work with aluminium-kerosine slurries has shown the optimum concentration of a gelling agent and a surface-active agent. A simulated reheat rig has been built, but further work on slurries may be centred on magnesium in view of the deposition difficulties[T46, T47].

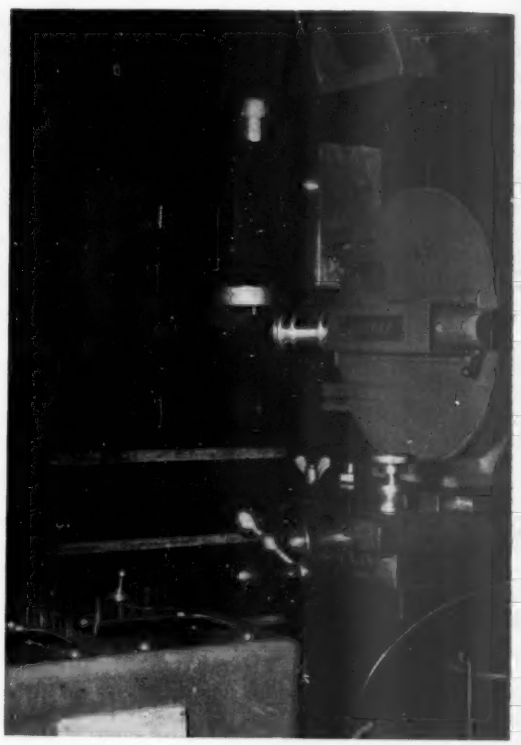

FIGURE 19. Investigation of plastic flow and final rupture.

Department of Aircraft Economics and Production

This country has been slow to appreciate the benefits which can be obtained from the application of detailed scientific investigation into production processes. Significant changes have taken place during the past decade, and the attitude of the Universities, the Colleges of Technology, the professional institutions, and many of the leading engineering industries is now distinctly encouraging. The Department of Economics and Production of the College is taking its part in these

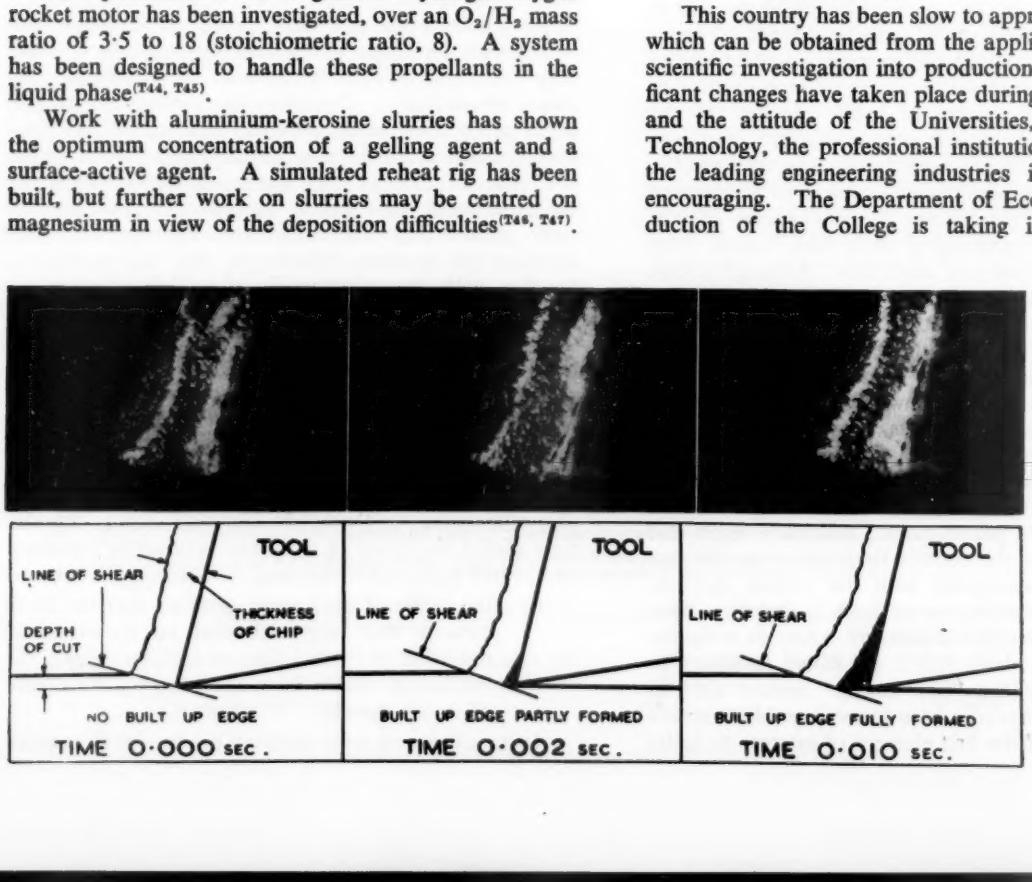

FIGURE 20. Formation of a built-up edge on face of tool.

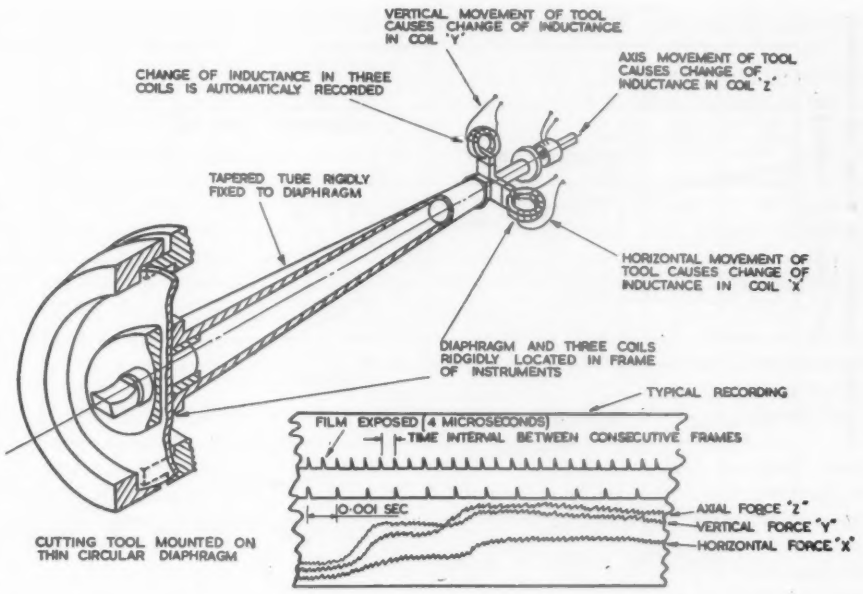
VERTICAL MOVEMENT OF TOOL CAUSES CHANGE OF INDUCTANCE IN COIL 'Y'
AXIS MOVEMENT OF TOOL CAUSES CHANGE OF INDUCTANCE IN COIL 'Z'
CHANGE OF INDUCTANCE IN THREE COILS IS AUTOMATICALY RECORDED
TAPERED TUBE RIGIDLY FIXED TO DIAPHRAGM
HORIZONTAL MOVEMENT OF TOOL CAUSES CHANGE OF INDUCTANCE IN COIL 'X'
DIAPHRAGM AND THREE COILS RIDGIDLY LOCATED IN FRAME OF INSTRUMENTS
TYPICAL RECORDING
FILM EXPOSED (4 MICROSECONDS)
TIME INTERVAL BETWEEN CONSECUTIVE FRAMES
0·001 SEC
AXIAL FORCE 'Z'
VERTICAL FORCE 'Y'
HORIZONTAL FORCE 'X'
CUTTING TOOL MOUNTED ON THIN CIRCULAR DIAPHRAGM

FIGURE 21. Principle of mechanical operation of cutting tool dynamometer.

developments and examples from its research programme are discussed.

The arrangement used for investigating the plastic flow and final rupture of material during a normal machining process is shown in Fig. 19, and Fig. 20 is a section of a film taken on the equipment where the machining speed was 60 ft./min., film speed 2,000 frames/sec. and exposure time 4 microseconds / frame. This section of film illustrates the formation of a built-up edge on the face of the tool, a phenomenon which occurred on three separate occasions during a test run of less than one second. This type of data is supplemented by simultaneous and accurately synchronised high speed recordings of the magnitude, direction and sense of the three components of the force acting on the cutting tool during the experiment. The cutting tool dynamometer used is a development of a commercial instrument and was designed and manufactured in the Department with special consideration being given to the production of a device with very low hysteresis losses and a very high natural frequency of vibration. The instrument section of the Electrical Department of the College designed and manufactured the three electrical measuring elements, illustrated in Fig. 21, and the electronic equipment used for connecting the output from the instrument to five channels of a standard six channel high speed recording cathode ray oscilloscope. When the optimum tool shape has been developed, supplementary experiments are likely to provide reliable information on optimum speed and feed for a predetermined tool life and this type of data is likely to become of increasing importance with the development of tape-controlled machine tools. One especially interesting investigation has been the development of a milling cutter to carry out the final machining operation on high tensile steel parts which have distorted during the final heat treatment operation.

Research is also being carried out in the recently organised High Precision Laboratory and is providing results which will enable a new assessment to be made of the total costs of manufacturing highly accurate mechanisms. Detailed analysis into so-called high precision equipment frequently reveals that many of the component parts are in themselves of relatively poor geometric shape and the high precision is confined to the relative size of one part referred to another.

One section of the research is directed to the manufacture of parts of good geometric shape and accuracy of size. When this condition is satisfied the parts comprising an assembly can be carefully fitted together without any adjustment in the size of one part to make it suit the size of another. The total cost of manufacturing a complete mechanism on this basis can be less than manufacturing the equipment from inferior parts because the slightly increased cost in producing the high precision parts is less than the cost incurred in adjusting one part to suit another.

As an example of the standards of accuracy now being attained, a shaft 1 in. in diameter and 4 in. long can be ground to an accuracy of ten millionths of an inch (0·00001 in.). This British machine is housed in the High Precision Machine Tool Laboratory of the College where automatic control is applied to the temperatures of the room, the cooling liquid, the hydraulic oil and the lubricating oil. The finish grinding cost is about 30 per cent higher than the cost of grinding the same shaft to a tolerance of one thousandth of an inch (1,000 millionths, 0·001 in.). Since this final grinding operation accounts for only about 20 per cent of the total manufacturing cost, the increase in the total cost is only 6 per cent.

The techniques being developed, with the support of the machine tool industry, are applicable to parts made as single components, small batch quantities and mass production.

Supporting mathematical work by statistical analysis has been carried out in the Department on the effect of the fit produced by the random assembly of parts made to predetermined tolerances.

INVESTIGATION INTO THE RELATIONSHIP BETWEEN MAN HOURS REQUIRED FOR THE MANUFACTURE OF AERO ENGINES AND THE NUMBER OF ENGINES MANUFACTURED

It is generally known in the Aircraft Industry that a relationship exists between the man hours (y) required to manufacture a particular aircraft, of the form $y=ax^{-b}$, where x is the serial number of the particular

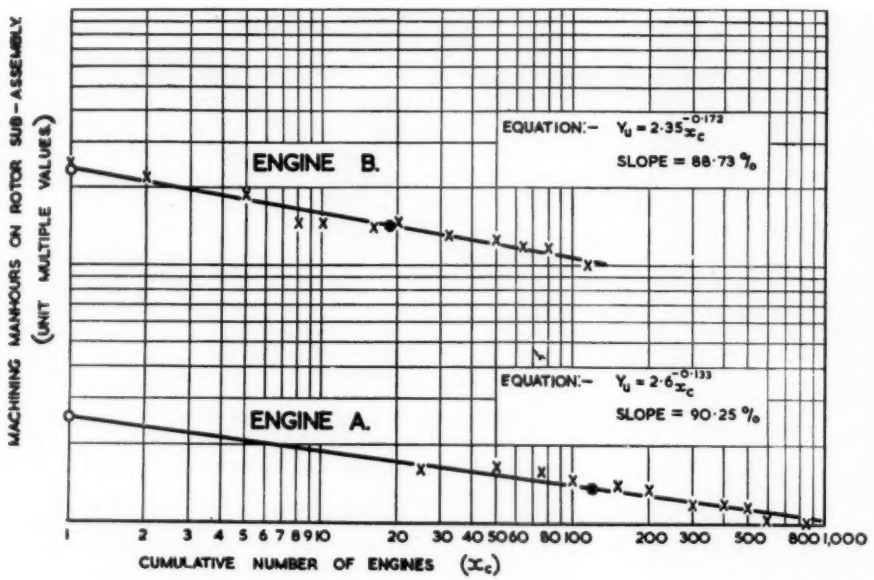
MACHINING MANHOURS ON ROTOR SUB-ASSEMBLY (UNIT MULTIPLE VALUES)
ENGINE B.
EQUATION:- $Y_u = 2{\cdot}35\,x_c^{-0{\cdot}173}$
SLOPE = 88·73 %
ENGINE A.
EQUATION:- $Y_u = 2{\cdot}6\,x_c^{-0{\cdot}133}$
SLOPE = 90·25 %
1 2 3 4 5 6 7 8 9 10 20 30 40 50 60 80 100 200 300 500 800 1,000
CUMULATIVE NUMBER OF ENGINES (x_c)

FIGURE 22.

aircraft, and a and b are constants. One common form when $b=0{\cdot}32$ is characterised by the simple relationship that the number of man hours required to manufacture the $2N$th aircraft is 80 per cent of the man hours required to manufacture the Nth aircraft.

Little is known of the corresponding relationships for aero engines, and for machining as distinct from assembly. Investigations conducted at the College on data related to some modern aero engines indicate that the slope for machining operations approximates to 90 per cent, and for assembly man hours 84 per cent. Figs. 22 and 23 show the data plotted on log-log scales.

DEVELOPMENT OF PHOTO-SAMPLING TECHNIQUES FOR THE STUDY OF LARGE WORKING GROUPS

The work study of large groups or teams of workers by visual observation has presented serious practical difficulties. Investigation at the College has shown that these difficulties can be avoided by photo-sampling techniques of recording and analysing the methods of performing industrial operations by groups of work people. Instead of a number of work study observers, a ciné camera is used, actuated by a pulsing device. Exposures are made at each pulse and the time interval between pulses may be fixed at from 1 to 10 sec. depending on the nature of the work being studied.

One of the interesting features of this research has been the construction and use at the College of a random interval pulse machine. This machine provides pulses to an electrically operated camera at random intervals and from the subsequent analysis of the film, ratios of the component elements of the work can be evaluated. To facilitate the exact identification of the work being performed each randomly spaced pulse triggers a mechanism which operates the camera for a few frames at ½ sec. intervals. Some of the equipment necessary for this technique is now becoming commercially available[T48-50].

OPERATIONAL RESEARCH

In the field of stock control, research is being carried out on the effect of variable delivery times and variable usage rates on the probability of running out of stock. It is hoped from this research to develop a simplified method which can be used by industry to achieve a much greater degree of control without appreciably changing the capital tied up.

Activity sampling, using complex statistical and operational research techniques, is extensively used in Work Study. It has recently been suggested that this technique is often misapplied. The College is at present engaged in research in an attempt to develop a more efficient method of sampling. Such a technique has now been developed and is in the process of being tested both under laboratory conditions and in

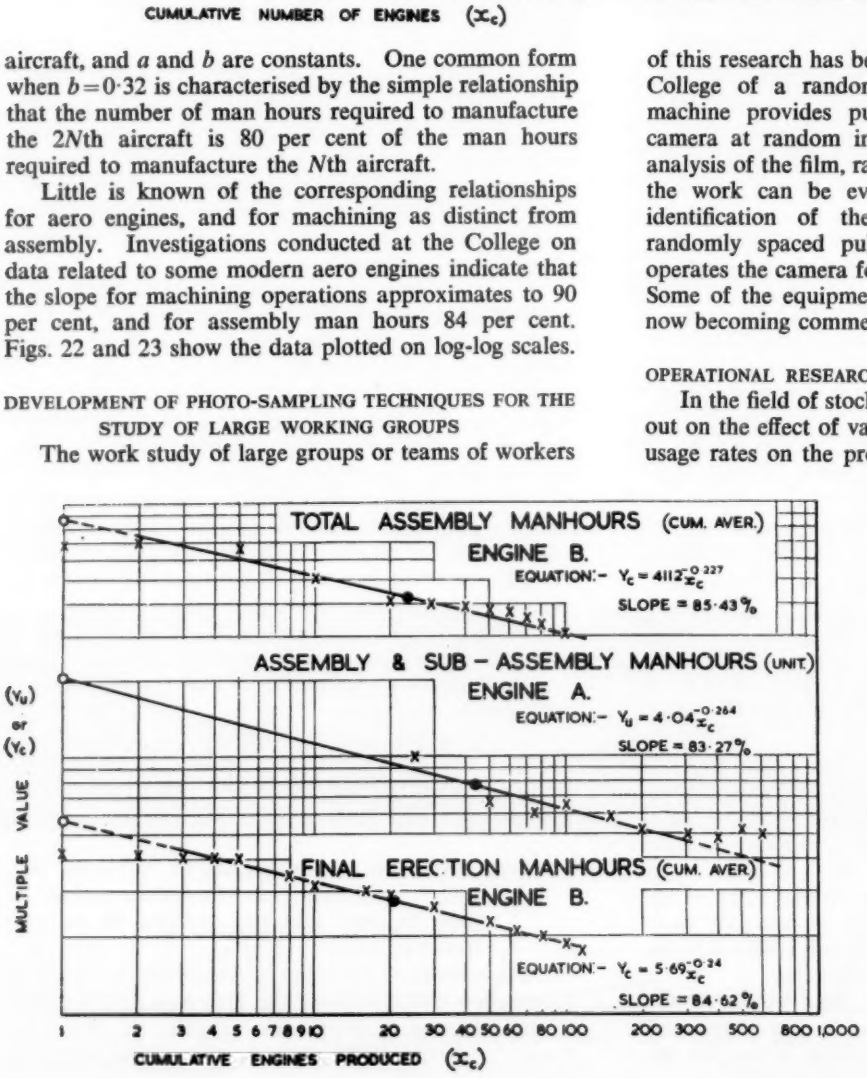
TOTAL ASSEMBLY MANHOURS (CUM. AVER.)
ENGINE B.
EQUATION:- $Y_c = 4112\,x_c^{-0{\cdot}227}$
SLOPE = 85·43 %
ASSEMBLY & SUB-ASSEMBLY MANHOURS (UNIT)
ENGINE A.
EQUATION:- $Y_u = 4{\cdot}04\,x_c^{-0{\cdot}264}$
SLOPE = 83·27 %
FINAL ERECTION MANHOURS (CUM. AVER)
ENGINE B.
EQUATION:- $Y_c = 5{\cdot}69\,x_c^{-0{\cdot}24}$
SLOPE = 84·62 %
MULTIPLE VALUE (Y_u) or (Y_c)
1 2 3 4 5 6 7 8 9 10 20 30 40 50 60 80 100 200 300 500 800 1,000
CUMULATIVE ENGINES PRODUCED (x_c)

FIGURE 23.

actual industrial applications. The methods developed will be introduced into the teaching of the Department and of the Work Study School.

In addition to these applied research fields a long term research programme on the factors affecting human reaction time to various stimuli has been started, the work being done jointly by the Department and the Work Study School. To date it has allowed the establishment of an operator's reaction to a light stimulus and has led to the measurement of changes in his reaction time when he is asked in addition to make decisions. It is hoped from this research to establish the relationships between factors which affect reaction time.

STATISTICAL RESEARCH

Using a hole and a shaft as specific examples, a statistical study has been made of the effect, on the extent of rejection or acceptance, of making parts when these are based on either, (*a*) separate limits on the parts themselves at the manufacturing stage, or (*b*) clearance limits representing the combination of those of (*a*), at the assembly stage. Two types of distribution of part sizes, the normal and rectangular, are considered over the range of possible manufacturing precision and comparison made at a specific level using Standard Tables. Mathematical and Monte Carlo procedures are revealed and economic considerations treated[66].

Department of Aircraft Electrical Engineering

The Department was established in 1955. Before this date there were limited facilities in electronics, machines and radio and radar in Design Department. Since 1955 the Department has grown rapidly as regards both Staff and equipment. It is divided roughly into electronics and physics, radio and radar, machines and power systems, and control and computation, the latter being the strongest. At first the attention of the staff was concentrated mainly on the establishment of laboratories and new courses, but lately some schools of research have taken shape. The first school, beginning before 1955, was in network theory and this continues to maintain interest. The largest school is in computer techniques, particularly in those which combine the advantage of classical analogue and digital methods. A third school, in microwave techniques, is concerned with the difficult problem of measuring the currents induced in irradiated sheets. In the remaining fields research has been confined to the work of individual students.

It is to be expected that the amount of long term research undertaken and the results obtained will increase considerably, and the Department is well equipped for such work. There are now established laboratories concerned with servomechanisms, analogue computing, digital techniques, process control, electronics, U.H.F. and V.H.F. techniques, microwaves, motors, servo components and power systems.

HIGH SPEED HYBRID DIGITAL ANALOGUE TECHNIQUES (Refs. 67, T53, T61–T63)

The two basic types of computer in general use are the electronic digital machine and the electronic analogue machine. Essentially the digital computer does sums in simple discrete steps (digits) whereas the analogue computer draws a graph and uses continuous variables. The accuracy of a digital computer can be made as high as desired at the expense of a lower computing speed, since each digit movement occupies a certain time interval. Generally the speed is too low for operation in real time simulation of systems involving physical components and human operators. The digital computer is extremely versatile since it permits the problem to be split into a large number of simple arithmetical operations.

Analogue machines are much faster and can operate in real or even speeded-up time. The accuracy, however, is restricted to that of the physical components. Such machines also lack versatility because integration can only be performed with respect to time.

A new kind of computer has recently been introduced, termed the digital differential analyser, in which the individual mathematical operations are performed in a digital manner in discrete blocks, but in which the latter are interconnected to represent the particular mathematical model in a way similar to that employed in an analogue machine. The basic idea of this machine is an attempt to combine the accuracy of the digital machine with the high speed operation of the analogue machine. Developments in this field are mainly aimed at increasing the computing speed of the digital integrator which performs the operation $\int y\,dx$ where y and x are variables.

Work at the College has been mainly devoted to an alternative approach, particularly with regard to problems in which computing speed is more important than accuracy. The fundamental object of the method is again to perform the mathematical operation $\int y\,dx$ and so to remove the limitation of the conventional electronic analogue machine. Hybrid analogue digital techniques are used, however, to retain computational speed at the expense of accuracy. $\int y\,dx$ is obtained from the indirect operation $\int_0^t y \frac{\partial x}{\partial t}\,dt$. One variable x is quantised by using one of several types of pulse modulation to give $\partial x/\partial t$ and the latter is multiplied by y in a pulse modulator to give $y\,(\partial x/\partial t)$. The integration with respect to time may then be carried out with a conventional analogue integrator or a digital integrator.

Theoretical assessment and construction of prototype versions of a quantiser and a high speed digital adder have been the subjects of two student theses. Further work will be carried out on problems concerned with the pulse modulator and with the operation of the complete integrator. The provision of such units will considerably ease the problem of simulating non-linear systems, on a real time basis.

MODULATED CARRIER FEEDBACK CONTROL SYSTEMS (Ref. 64)

The extension of root locus techniques in the design of a.c. servo-mechanisms is under investigation. Universal charts giving limits of possible performance have been compiled for simple systems. The feasibility

of obtaining root and phase angle loci by automatic computing aids is also being considered.

OPTIMUM DESIGN OF CONTACTOR SERVO-MECHANISMS

A theoretical investigation of the optimum design parameters for contactor servo-mechanisms has been undertaken. Initial consideration is being given to the determination of predictor networks to enable the system to perform the particular task in the minimum possible time when subjected to simple types of input signals. Simulator studies of particular systems are also in progress.

BOOLEAN ALGEBRA (Ref. T66)

The mathematical expression of logic proposed originally by George Boole in 1847 has been the subject of considerable study since 1939, this interest having been aroused by a realisation of its applicability first to telephone switching problems and later to the systematic design of digital computers. By its use the solution of such problems is largely removed from the realm of experience and intuition.

The basic principles of the algebra are very simple but when used to describe the possible configuration of n switches the number of expressions generated is a double exponential (2^{2^n}) and one of the chief pre-occupations of writers in this field has been the simplification of these large numbers of expressions so that when translated into hardware a minimum of components need be used.

All the most important methods of simplification have been systematically studied at Cranfield and a new method has been proposed which is more easily applicable than the others when n is greater than about 5. Clarification and extension of the present concepts of geometrical representation in n-space of the Boolean expressions has been carried out, as well as exploratory work on two distinct forms of matrix which promise to be of importance in the study of another outstanding problem, that of the *ab initio* synthesis of switching networks, especially those incorporating time delays.

Other topics touched upon are the modification of the algebra to encompass undirectional switches (*i.e.* rectifying elements) and the possibility of reducing all problems to the study of a limited number of "symmetric switching functions" which may be constructed so as to imply all the remaining functions of interest.

A GRID-CONTROLLED PHOTOMULTIPLIER (Ref. T52)

It has been known for some time that very high voltage gains could be obtained from single thermionic valves by incorporating a system of secondary emission electrodes so as to multiply the original current (and its fluctuations) by factors as high as 10^6. This investigation was carried out to discover whether a photo-emissive cathode could be substituted for the more usual thermionic emitter and what advantage, if any, might accrue (Fig. 24). Various kinds of illumination were used to excite the photo-cathode, whose emitted electron current was controlled as in a conventional valve by the potential on an adjacent grid. Light of various wavelengths and a scintillator energised by a strontium 90 source were all tried. Direct injection of electrons from the strontium 90 without the intermediary of a scintillator was not satisfactory. Limitations of power dissipation have necessitated a pulsed method of operation to achieve the order of transfer conductance expected, but up to the present time shortcomings in the physical structure of the available tube has limited the transfer conductance to about 70 mA. per volt compared with about 10 mA. per volt for a conventional high-g_m thermionic valve.

SOME TRANSISTOR APPLICATIONS (Refs. 68, 69, T53-T55, T66, T68)

The relatively recent surface barrier transistors have been used in an attempt to achieve very high speed adding in digital computers. A parallel mode has been employed and the carry propagation time for a digit binary addition has been reduced by the combination of a novel form of logic and the fast transistors to 1·0 μsecond. The total addition time is 3 μseconds, a figure so far substantially superseded only by circuits using the newer and very expensive micro-alloy transistors[T53].

The possibility has also been investigated of using a transistor to detect very small degrees of motion. A

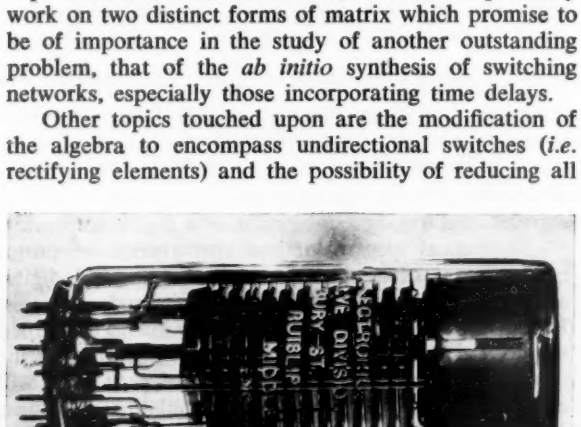

FIGURE 24. Grid controlled photomultiplier.

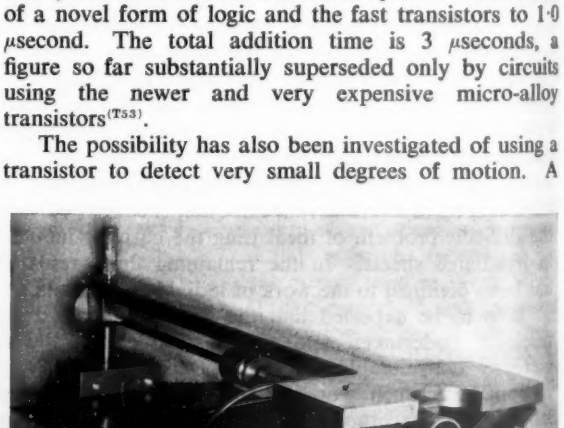

FIGURE 25. Relative motion mechanism.

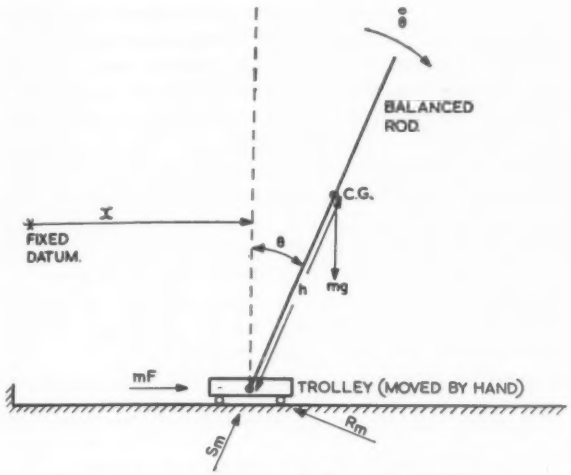

FIGURE 26. The dynamics of the balancing system.

p-n junction is subjected to a beam of α-particles and emits pulses which may be counted. Small displacements of the very small sensitive area relative to the beam result in changes of the count (Fig. 25). The results suggest that, with modifications, displacements of 0·00015 in. could be detected by counting over a period of 25 sec.

The phenomenon of hole storage in a saturated transistor has been put to use in the design of a simple and economical pulse width modulation system suitable for missile and aircraft telemetry. The hole storage time is governed by the base input current which in turn is a function of the variable to be telemetered. An accuracy of 3 per cent with inputs in the range 0 to 1 has been achieved.

VARIATION OF YOUNG'S MODULUS WITH TEMPERATURE
(Ref. 70)

Accurate measurements of Young's modulus at temperatures between 20°C and 1,000°C have been made for all the Nimonic alloys by a magneto-strictive method which detects the change in the delay time of a stress pulse travelling along a wire of the material under test.

THE TRANSFER FUNCTION OF A HUMAN OPERATOR
(Ref. T56)

There have been many attempts to measure the characteristics of the human operator. The study of his behaviour in performing some task of control may be vital, particularly in relation to certain aircraft pilot and missile command link systems. It was desired to devise an experiment which would be sensitive to the form of the human transfer function under chosen conditions. The experiment designed to meet these requirements takes the form of a rod which has to be balanced on end. In this the operator is forced to a high degree of concentration to perform a pleasant and amusing task and the risk of vitiation of the test through boredom is diminished. To provide a consistent and manageable experiment the rod is pivoted to constrain rotational movement to one plane only on a carriage which moves

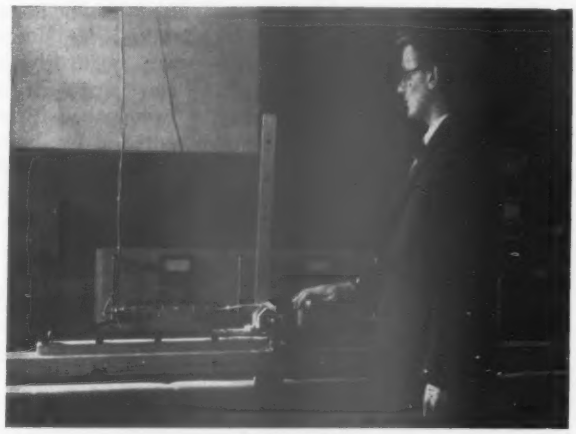

FIGURE 27.

to and fro on a track in the same plane (Figs. 26 and 27). On suddenly freeing the carriage and rod from constraint in the position of unstable equilibrium, recordings are taken of the angular motion of the rod and the linear travel of the carriage while the operator maintains the rod in a state of balance. By analysing the waveforms generated by the operator plus system during the time he is maintaining balance it is hoped to determine some significant parameters concerning his response. Preliminary tests have confirmed the feasibility of the method, and have shown that the accepted approximations to the human transfer function are not adequate to describe the performance of this task.

ELECTRIC NETWORK THEORY
(Refs. 71–72, T57–T60, T68)

The two fundamental problems of network theory are analysis and synthesis. Network analysis is the determination of the response when the network and excitation are prescribed; network synthesis is the determination of the network when the excitation and response are prescribed. Both problems have received attention at Cranfield.

Recent developments in network analysis have led to a systematic process which is both powerful and flexible. The mathematical basis to this new approach is a combination of matrix algebra and the combinatorial topology of linear graphs. Most of the work in this field has been confined to the study of networks in the sinusoidal steady state but at Cranfield the method has been extended to include network response in the time domain and to include the case of networks containing active elements such as thermionic valves and transistors.

The problem of network synthesis has three aspects: approximation (the determination of a physically realisable function which satisfactorily approximates the desired network behaviour); realisation (the determination of a network corresponding to the given approximant); and equivalence (the determination of all networks electrically indistinguishable but structurally different from a given realisation). Each of these aspects has been the subject of students' theses. Two graphical

techniques have recently been devised to facilitate approximation; a procedure for synthesising single energy 2-port networks according to prescribed driving point and transfer functions has been proposed; a method for synthesis according to prescribed time response has been developed; and an attempt has been made to generalise the Howitt-Burington theory of equivalence to yield equivalent networks with different kinds of elements.

SURFACE CURRENT MEASUREMENT (Refs. T69–T71)

A general interest in suppressed aerials in 1955 developed into an interesting programme of basic research into the measurement of radio frequency currents in metal surfaces.

The notch aerial in its simplest form is an open-ended slot cut into the edge of a metal sheet. This is an attractive proposition as an aircraft aerial; it can be cut into the edge of a stabilising fin and covered with a dielectric so as to present the external contour required by the aerodynamicist. When this aerial is excited, current can be driven through the skin, and the whole aircraft can be likened to a flying aerial.

Knowledge of the current distribution around a notch was only available for the impracticable case of an infinitesimal notch cut into a semi-infinite sheet; other conditions of notch are not amenable to analytical treatment. The initial problem was to develop a current measurement system and to investigate the distribution about a finite slot cut into a plane sheet of finite dimensions.

A convenient sheet of dimensions 122 × 244 cm. was used and slots were cut into the centres of the broad and narrow sides; slot depths investigated extended to some 18 cm. The energising transmitter produced some 100 watts at 180 cm. wavelength.

The surface currents were detected by a hand probe based on a loop aerial; the elimination of stray pick-up was a severe problem and the loop was made as small as possible so as to indicate more nearly the current at a point on the surface. The final loop design is shown in Fig. 28. The loop diameter of 1·3 cm. (0·00725 wavelength) is considered to be the smallest practicable size

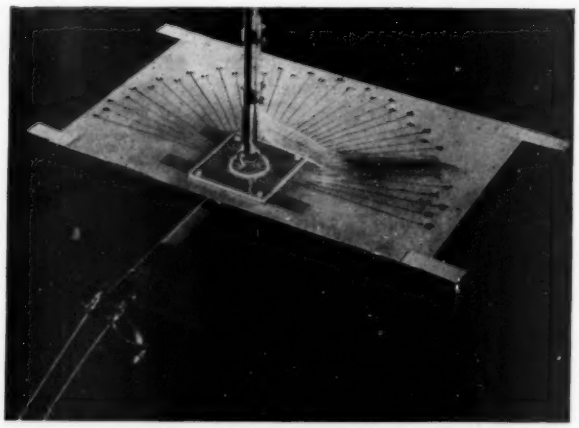

FIGURE 28. Pick-up loop.

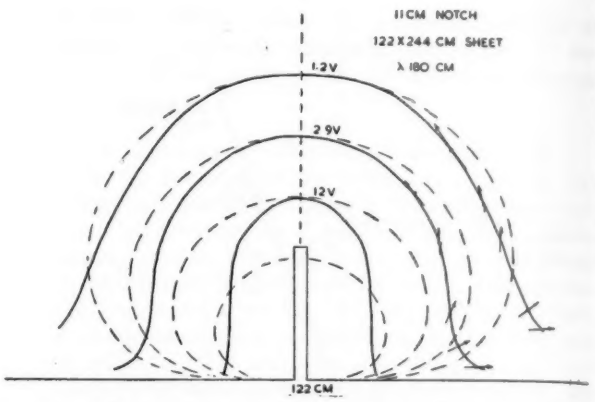

FIGURE 29. Current contours measured round an 11 cm. notch.

capable of yielding useful information in this type of work. Fig. 29 shows, in solid line, the current contours measured around an 11 cm. notch, arrows showing the direction of current flow, and the broken line the theoretical current contours on a semi-infinite sheet. The effect of the finite size giving rise to currents flowing parallel to the edge can be seen clearly and if the length is resonant at the applied frequency then high standing waves can exist on this edge and efficient radiation of energy can occur.

Some success having been achieved with the energised sheet, attention was turned to the measurement of currents induced in a sheet when irradiated by an electromagnetic wave. A knowledge of the induced current distribution would lead to a better understanding of the phenomenon of electromagnetic scattering by conducting bodies of complex geometry. The main interest is in bodies whose dimensions are several wavelengths long, so for experimental convenience work was carried out at wavelengths of 3 and 10 cm.

At these wavelengths a loop aerial of the smallest practicable dimensions (some 1¼ cm. diameter) would be responsive to too great an area of surface (in terms of phase) and it was considered that better results could be obtained by other methods. In consequence measurements were made using a re-radiating probe and a slotted line.

The re-radiating probe takes the form of a movable unipole aerial capacitatively coupled through its base to the conducting surface and radiating a wave having a quadrature polarisation to the incident waves. The slotted line is a coaxial line constructed within ½ mm. bore hyperdermic tubing short-circuited at the remote end with a single transverse slit pick-up cut near the short circuit. The line is placed on the surface, so causing the inner conductor to be inductively coupled to the sheet through the slit. Present work is devoted to obtaining a "standard" surface having a known induced current distribution. As soon as a mechanically realisable standard is determined a comparison apparatus will be developed to investigate the various possible forms of pick-up devices to ascertain the accuracies achievable in both the magnitude and phase measurement of induced currents.

HYSTERESIS MOTOR (Refs. T72–T75)

The hysteresis motor is unlikely to be a competitor of the more widely used a.c. motors for general applications, but its unusual characteristics make it very suitable for certain drives such as gyroscopes in guided missiles. Little has been published on the theory, although the mechanism of torque production at speeds between standstill and synchronism has been understood for some time. The objects of this further work were:—

(*a*) to establish design criteria for the rotor material and air gap structure and configuration,

(*b*) to examine the performance near synchronous speed with regard to establishing the mechanism by which synchronism is achieved by the rotor,

(*c*) to examine the effects of harmonics on the air-gap field distribution,

(*d*) to examine the significance of the eddy current torque on hysteresis motor performances.

From a purely theoretical standpoint, eddy currents are extraneous to an investigation of hysteresis motors, as also are air-gap field variations. However, since the hysteresis torque is proportional to the volume of magnetic material in the rotor, and the eddy current torque is proportional to the surface area of the rotor bounding the air-gap, only in large machines will the eddy current torque be negligible. Thus it is necessary to study the combined effects.

Analysis of the relationships between the time and circumferential variations of flux density and applied magnetomotive force leads to results which are similar to the torque equation as derived by Teare, but in a much more useful form. Fourier analysis applied to the *B-H* integral thus obtained indicates that the hysteresis torque is dependent on three parameters, only one of which, (the space angle between the fundamentals of *B* and *H*) is variable in any particular motor configuration. The method has been extended to establish the mechanism by which synchronism is achieved by the rotor. This involved solving the equation of motion of the rotor; although this equation is inherently non-linear, a process of linearisation has allowed a solution to be obtained. This has been checked with a simulation study, and an experimental investigation has been undertaken to explore the transient performance of two different motors. Some difficulty has been found in measuring the transient values of the torque, and quantitative correlation with the theoretical expressions has not been attempted so far. The qualitative indications nevertheless support the theory developed, and work is proceeding to obtain positive experimental verification.

TWIN 150 H.P. GENERATOR DRIVES

In order to take part more effectively in the development of new aircraft electrical power systems, two electrically driven Ward-Leonard systems each of 150 h.p. have been installed and will shortly be commissioned. This power can be developed at any speed between 2,100 r.p.m. and 12,500 r.p.m., the value of speed being maintained constant within ± 1 per cent of the selected value at any load between zero and full load.

Department of Aircraft Materials

The main researches in the Department at the present time are particularly related to the question of metal fatigue. In this context, work is being undertaken with the support of the Ministry of Aviation on the high strength aluminium-zinc-magnesium alloys, which have an unexplained low ratio of fatigue limit to tensile strength. There is a strong suspicion that this is in some way related to the characteristics of precipitation in these alloys, and one suggestion is that the action of the alternating stresses causes the precipitates, in certain very small localities, to go back into solution. These softened regions are then thought to be the regions in which the initial fatigue cracks are created.

The Departmental work has been concerned, in the first place, with studying the fatigue characteristics of such alloys when these are deliberately under-aged or over-aged by thermal treatments before the fatigue stressing is commenced: that is, the process of precipitation is initially either not developed at all or over-developed beyond the optimum state. In both cases the fatigue life is somewhat reduced for a given stress, but the fatigue limit changes very little. It is hard to see on this basis how the relatively low fatigue limit can be due to a re-solution mechanism in a small locality if the virtually complete solution of precipitates (by the inhibition of the precipitation process) has very little effect. This result does not, however, completely dispose of the re-solution hypothesis, which may still be the determining factor.

Attempts have been made to modify the nature of the precipitate distribution by stressing the alloys for short periods between the actual solution treatment and the ageing. Such periods of either alternating or static stress accelerate the rate of ageing and, in certain cases, actually make possible a greater final hardness than that achieved without such intermediate stressing. Whether this state is also one of better fatigue resistance is a question which is now being examined.

A great deal of work has also been carried out on the electrical resistivity changes which occur in the aluminium-zinc-magnesium alloys during ageing and fatigue. These results are a little complex to summarise in a short space, but emphasis may perhaps be placed on two points. Firstly, it has always been accepted that the rate at which precipitation occurs is directly related to the concentration of vacancies (on the atomic scale) in the metal. If this concentration is increased—as it can be by the kind of intermediate stressing already noted—then the subsequent rate of precipitation increases, as observed. This would also be expected to be true for the case where precipitation is actually occurring simultaneously with the application of an alternating stress. Measurements on electrical resistivity suggest that for these high strength light alloys, at least, the rate of precipitation is *retarded*. This is a quite unexpected result, and may well support the hypothesis that resolution occurs in these alloys under alternating stress, effectively delaying the opposite process of precipitation. These results are now being checked by comparison with the behaviour of other aluminium

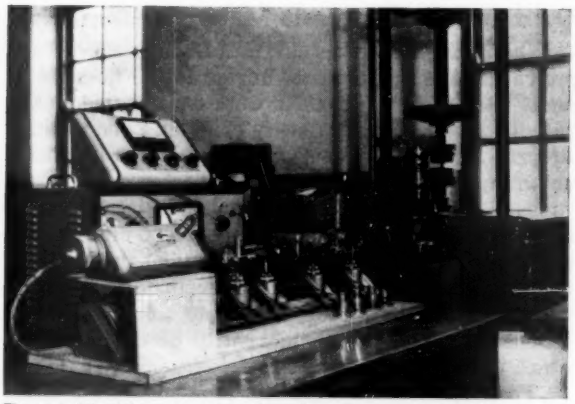

FIGURE 30. Measurement of surface attenuation during ageing and fatigue. (The tubular test piece is shown mounted in grips, but disconnected from the fatigue machine.)

alloys which show good ratios of fatigue limit to ultimate stress, such as the 4 per cent Cu alloy.

A new technique has been developed and applied to the study of the surface changes that occur under fatigue. Basically, the method involves working with a test piece in the form of a wave guide, the change of attenuation of radio waves in the wave guide being measured during the course of fatigue (Fig. 30). While the technique in itself is not difficult in principle, the achievement of the required level of accuracy and reproducibility has involved a great deal of refinement and control. The actual attenuation offered by test pieces of practicable size (that is, a few inches long) is so small that changes in this attenuation are extremely difficult to measure with the required degree of accuracy. It is, however, hoped that measurements of this kind will be able to elucidate whether or not changes occur in such alloys very near to, or actually at, the surface (the depth of penetration of the micro-waves is about one micron at the frequency used) even though the main bulk of the material is unaffected. This again relates to the re-solution proposition, which suggests that fatigue is initiated in very localised surface regions.

Other work of a more technological nature is concerned with the improvement of castings by the application of mechanical vibrations during the solidification process. Recent results on a steel (H.R. Crown Max) show that if the frequency of vibration is correctly chosen a finer and more uniform grain size is achieved with consequently improved mechanical properties. The tensile strength is raised from 40 to 45 ton./in.^{2}, the elongation from about 30 to 40 per cent and the impact strength from 7·5 to 10 ft. lb. (Refs. 73 and 74).

New research lines are now being established concerned with the properties of beryllium, up to about 400°C, and with the structural alloys of aluminium, magnesium and titanium under the conditions likely to be encountered at the skin of a Mach 2 vehicle. As it happens, both these projects raise fundamental issues in what is known as *recovery*, a general term which embraces a number of processes by which metals recover, or tend to recover, their original properties after some kind of treatment, such as mechanical working. Stress relaxation is, of course, an obvious example of this type of behaviour. In the case of the Mach 2 skin materials these processes may be further complicated by special metallurgical changes associated with precipitation, and these may exert a serious influence on the way in which such materials may be utilised.

Department of Mathematics

During the past few years, some investigation of wave drag of bodies in supersonic flow has been carried out in the Department. This has led to the formulation of what is now known as the "transfer rule" for calculating the wave drag of winged bodies and the minimisation of this drag, and to a general method of dealing with drag calculations for both lifting and non-lifting bodies which has become known as the "harmonic method." In addition, methods for the numerical calculation of drag of slender bodies and of lift and drag of wings at supersonic speeds have been investigated[75, 76].

Other topics which have received attention are wing-tailplane flutter, for which numerical computations have been made, and the development of special vector integral identities for the integration of vector differential equations. The Department has also carried out various small investigations for the benefit of other members of the College staff, including numerical computation in many cases.

In the future, it is hoped that the Department will engage in the development of computational methods and techniques for application in all branches of aeronautical engineering.

Department of Flight

The primary teaching subjects in the Flight Department are stability and performance with the associated problem of instrumentation for their measurement. This leads naturally to research in these two fields which lean heavily on the third for their solution. Aircraft available include a de Havilland Dove, a Morane Saulnier 760 and two Avro Ansons.

STABILITY

For a number of years work has progressed in the Department on the measurement of dynamic stability. The problem appears simple enough in that the motion of an aircraft can be expressed in terms of a set of simultaneous equations of the second order and it is only desired to find the constants of three equations. The method most widely used was developed by Cornell Aeronautical Laboratory and consists of a harmonic analysis of the control input function and of the resultant output in terms of aircraft response. In practice the results obtained by this technique, at the College, have proved moderately acceptable in the longitudinal mode but not at all satisfactory for the lateral modes. In fact many authorities have strong reservations about the validity of the analysis.

Because of this failure of the lateral tests a new technique has been tried which is much simpler to apply

and makes greater use of the data obtained from flight tests. A primary characteristic of the lateral modes is the Dutch Roll Oscillation which is poorly damped on most aircraft. In such an oscillation the separate sums of rolling forces, yawing forces and side forces are normally equated to zero but, since the increments in each equation are not in phase, the most informative presentation is in the form of a force polygon using the maximum amplitude of the forces as modulus and their relative phase angles as direction.

From flight tests, the amplitude and phase angles of the variables (roll, yaw and lateral acceleration) are measured and all that is needed for a complete solution is to know the ratio of the derivatives. These are found from "steady state" manoeuvres such as straight sideslips, rates of roll and flat turns.

This technique for the measurement of lateral derivatives was in fact arrived at in reverse. An attempt was made to find the derivatives using the numerous "steady state" manoeuvres available in the lateral case *i.e.* straight sideslips, flat turns, turns on aileron only, etc. As might have been expected, these only give the ratios of the derivatives and some measure of frequency in the system is necessary to find their values in terms of the moment of inertia of the aircraft. This is where the vector presentation of the Dutch Roll has proved so useful.

Tests on the Dove have proved the method of analysis to be quite practicable and improvements are expected in the coming year by use of more sophisticated instrumentation. The aim from the beginning has been to avoid the use of estimated derivatives at any stage but to rely entirely on measured data. The system is to be used on the MS760 where there is the additional advantage that fuel can be used from one tip tank at a time giving a direct measure of the aileron rolling power —a key derivative in most lateral manoeuvres.

PERFORMANCE

Until the past few years almost all performance work has been done in straight and level flight, where the steady speed was measured against engine power using either the engine manufacturer's power curves or some torque measuring device. This technique is still taught in the Department but a need has been felt for an improved method making full use of the continuously recorded data instead of the present one of analysing a relatively few discrete points. The basis of the approach is that power (for a piston engine) and thrust (for a jet) remain almost constant with speed, whereas drag varies as the square of the speed and the square of the lift coefficient. Proceeding along these lines, it only seems necessary to vary the speed in an arbitrary manner by diving and climbing and to measure the aircraft's acceleration in the process.

Some preliminary tests have shown that the order of accuracy of instrumentation needs to be greatly improved and, until this is done, it is difficult to assess whether or not the method is practical. There are two methods available for handling the information. In one, high-speed read-out equipment can be used to measure numerous discrete points which would then be handled by a digital computer giving the best available fit for the material. A more elegant solution is to use a simple form of analogue computer in flight continually solving the speed and acceleration equation with an input of pitch attitude, best fit showing as an error between computed and measured speed. This type of system could be made self-regulating so that a proper statistical average of the drag characteristics could be obtained.

The continually increasing accuracy demanded of the instrumentation for dynamic stability work in the Department has led to the consideration of radical changes in the measurements of rates of roll, pitch and yaw. The conventional method has been to use rate gyros with precise damping characteristics. The resolution and the behaviour of the damping under flight environment leave much to be desired. The scheme suggested is to use free gyros for pitch, roll and yaw with digital pick-off in the form of Moire fringes giving accuracies of the order of seconds of arc. Rates can then be obtained, either directly or by subsequent laboratory analysis, using the time interval between pulses. The argument in favour of the free gyro is that its free wander rate is extremely low compared to the time interval of the dynamic flight manoeuvre and damping problems are eliminated.

Indeed the whole question of Flight Test Instrumentation must be carefully considered in view of advances in theory and in the systems of data handling. It is felt that the time has come to have a thorough investigation of present practice relating not only to the quantities measured but also to the accuracies of the final data. All too often vital small functions are concealed by frequency sensitivities, variable damping effects and calibration difficulties, and devices to overcome this must be developed. A typical example is the requirement for a three-axis accelerometer accurate to 0·03 ft./sec.^{2} with no cross coupling effects. The problem appears to have been solved in inertial navigation systems to orders of accuracy much greater than is asked for here.

The other problem is the recording of these data to the same order of accuracy. The present limitation is generally imposed by the paper width on trace recorders giving accuracies in the region of one per cent of full paper width, which, of course, is normally more than one per cent of full amplitude. This accuracy must be improved either by digital recording on paper or some other medium preferably in a form suitable for automatic data processing. It is hoped these problems will be enlarged upon in an Instrument Symposium in 1960.

FURTHER CURRENT RESEARCH

Lancaster

Tests on the Midge wing, (Fig. 31) mounted above the fuselage of the Lancaster, were successfully concluded in June 1959. The measurements on boundary layer transition due to sweep on this scale of model (8½ ft. span × 6 ft. chord) are proving useful in the design study of a swept wing for laminar flow. In addition the 120 pressure plotting points give a very

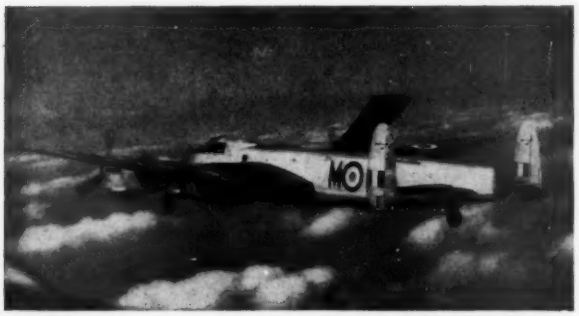

FIGURE 31. Lancaster with Midge wing on mid-upper fuselage.

detailed picture of the pressure distribution for comparison with theory[76, 77]. The work on swept wings is to continue with a model designed to investigate the suction parameters necessary to maintain laminar flow. It will be mounted above the Lancaster and flying should begin early in 1960.

R.A.E. Thurleigh

In the session 1959/60 a combined experiment was undertaken with Aero Flight at Thurleigh. The Department manufactured a number of outside air temperature probes (Fig. 32), each of different design, which were then fitted on a Hawker Hunter and flown from Thurleigh. The investigation was made to clear up some serious anomalies in the measurement of outside air temperature where characteristics appear to change with altitude[78]. The problem was completely resolved and the work has led to a new standard air temperature probe being adopted by the Ministry of Aviation.

It is hoped to continue this type of association with Aero Flight and it is proposed that this year a student should carry out a research programme on artificially induced buffet on a Venom.

Short Sherpa

Two years ago the programme of research on rolling response with all moving tips was brought to a premature end due to an engine failure. Both engines have now been modified and the programme on rolling response will continue during the present session. There is renewed interest in the Sherpa with the advent of hypersonic aircraft, not because of the isoclinic wing but because of the similarity in all moving tip controllers.

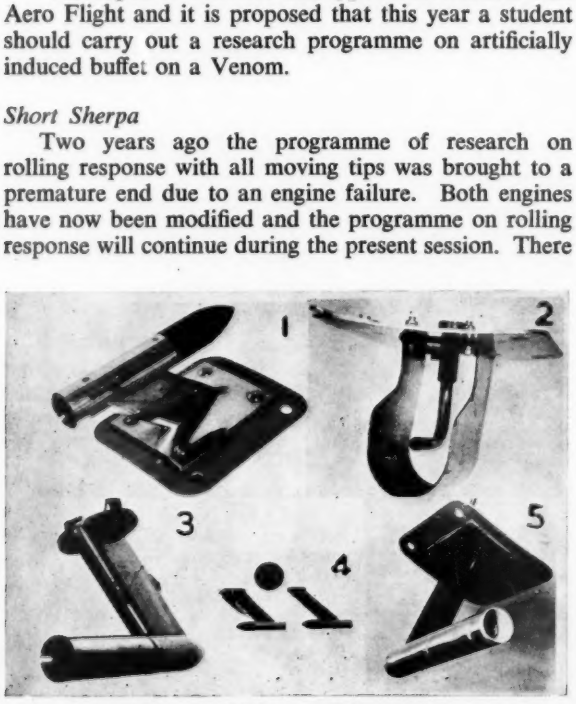

FIGURE 32. High temperature probes.

Library

DOCUMENTATION RESEARCH

For the past eighteen months, with the support of a grant from the United States National Science Foundation, an investigation has been proceeding into the comparative efficiency of various methods of indexing scientific and technical information[79]. The first stage of the programme will be completed in March 1960, when 18,000 documents will have been indexed by four different systems. The immediate objective of the project will have been attained about a year later when an intensive test programme will have been completed. It is now clear, however, that the data will be most valuable, after detailed analysis, for investigating the basic principles of indexing systems, and will assist in the design of systems which can be used for information retrieval by high speed computers.

Conclusion

The foregoing review has given an account of research either completed or in progress in nine divisions of the College of Aeronautics.

The College is not primarily a research institute. Apart from the work of Research Fellows and Assistants, the research is carried out by members of staff who have major responsibilities in teaching and by students, as a feature of their Course work. The suggestion is made from time to time that Cranfield might have a Research Division operating under the general direction of the College but somewhat detached in respect of organisation, so that the association between the two would be similar to that between, for example, Cornell University and Cornell Aeronautical Laboratory in the United States. The Cornell system necessarily involves engagement by the Aeronautical Laboratory in research as a large scale financial undertaking, with heavy reliance on commercial and state sponsors, the connection with academic instruction in the University becoming correspondingly tenuous. This arrangement is evidently acceptable in America and variations of it are in operation in most American universities and institutes of technology. In this country, the outlook of the educational establishments is different and it is believed that teaching derives the greatest benefit from research when the association between the two is most intimate. The relationship at Cranfield follows the characteristic British scheme and it is thought that it is best suited to present needs in this country.

Because of the part which research plays as a deliberate and essential component of the course of instruction, students, as has been described, have been engaged, to a greater or lesser extent, in most of the topics to which reference has been made. The theses, identified by the prefix "T" in the list of references, are illustrative of the contributions made by students to a large number of research projects. As with the first

year's post-graduate research in a university, the work in the Diploma course at Cranfield serves the double purpose of introducing men to the aims and methods of research and assisting the progress of continuing investigations.

The two circumstances, that the staff are not pre-occupied with teaching an undergraduate body and that the majority of the students have had a useful amount of practical engineering experience, greatly ease for the academic staff the task of organising and supervising the student's "thesis work" and pursuing their own advanced research. It is hoped that the range and quality of the research described in this paper will be considered to justify the general philosophy underlying its conduct.

The putative authorship of this paper presents a minor problem. As was mentioned earlier, the body of the text and the illustrations were contributed by the Departments named, the Heads of Departments responsible being:

Aerodynamics: Professor J. A. J. Bennett, D.Sc., Ph.D., F.R.Ae.S.

Aircraft Design: Professor W. S. Hemp, M.A., F.R.Ae.S.

Aircraft Economics and Production: Professor J. Loxham, C.G.I.A., M.I.Mech.E., M.I.Prod.E., M.B.I.M.

Aircraft Electrical Engineering: Professor G. A. Whitfield, B.Sc., F.R.Ae.S., F.Inst.P., M.I.E.E.

Aircraft Materials: Professor A. J. Kennedy, Ph.D., A.M.I.E.E., F.Inst.P., F.I.M.

Aircraft Propulsion: Professor A. G. Smith, A.R.C.S., B.Sc., D.I.C.

Flight: Wing Commander C. G. B. McClure, A.F.C., M.A., A.F.R.Ae.S.

Mathematics: Professor G. N. Ward, M.A.

Library: C. W. Cleverdon.

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DISCUSSION

Professor Mair: He would like to take this opportunity of reinforcing what Professor Murphy had said about the good relations between Cambridge and Cranfield; the planners of Cranfield thought very carefully about this when they decided to place it the same distance from Cambridge as from Oxford. With a fine sense of balance they made it just a little bit farther away from London.

He would also like to reinforce what Professor Murphy had said about research and particularly to agree with him about not having a research division on the lines of Cornell Aeronautical Laboratory. It might be a great pity if Cranfield started yet another division—which might be half way between Cranfield and Cambridge, but separated from everywhere. It was a most important feature of Cranfield that the research was so closely mixed up with the teaching.

The striking thing about Cranfield and about Professor Murphy's accounts of it, was the enormous range covered, from man powered aeroplanes to flight at ten or twenty times the speed of sound. This wide range left those present that evening free to ask questions about almost anything in engineering, especially since Professor Murphy had brought with him an impressive range of experts.

A Speaker: The only pictures that they saw of supersonic air liners had no windows. Was it now accepted that the supersonic air liners of the future were to have no windows?

Mr. Masefield: He could only say that in the supersonic transport investigations on which they were engaged at the moment there were windows. They were made of quartz, because of the heating problem, and some of these were being investigated in the Bristol 188 research high-supersonic aeroplane which, as they knew, would be flying before long; his own feeling was that passengers hated being shut up in "black boxes" and they must be allowed to have some orientation by giving them some windows. It was often said that there was nothing to see, but that was rubbish; at 60 or 70,000 ft. one could get some wonderful views of continents far below, clouds and the rest of it. It was well worth while looking out. The penalty in weight was not one that they had to worry about too much. It was heavier, of course, but not so heavy that they could not cope with it, and to give an attractive cabin was well worth while. The shape of the aeroplane, which varied just a little from the one illustrated, the one that his company was working on at the moment, did permit windows to be offered in the conventional sort of places.

A Speaker: To what extent was the use of spot welding on aircraft being investigated for stainless steel wings?

A. F. Newell (College of Aeronautics, *Assoc. Fellow*): The aircraft referred to by the questioner was projected as a Design Exercise in 1953. The wing was of multi-cell stainless steel construction and was puddle-welded. They had co-operated with the British Oxygen Company on the development and feasibility of doing such welding and produced a number of sample specimens. The "real" experience on this type of welding, however, was with Bristol's. The Bristol 188 was a "Secret" aeroplane, but if the chairman would like to comment on their practice the question could be answered. The point of interest from the point of view of the College was that theirs, a similar aeroplane, was being projected at the same time as Bristol, and their satisfaction had been to find since that they were thinking of identical methods of construction.

Mr. Masefield: The 188 was extensively puddle-welded and in fact had little riveting at all. Stainless steel welding had been one of the great problems in building this aircraft, in fabricating the structure almost entirely from welded stainless steel and getting double curvatures onto some of the forms in the very thick plates that had been used to overcome the heating and the "thermal thicket" problems that were going to be encountered. It seemed to be working out pretty well, in fact, and the surface finish had come out remarkably smooth: it could then be polished down to give an effect rather better than the best flush riveting could achieve. He thought that for more than a Mach 2.4 aeroplane they would have to have welded steel structures.

A Speaker: Was every weld inspected or was some sort of sample taken?

Mr. Masefield: Every weld had to be inspected.

Professor Murphy: The questioner had put his finger on one of the most interesting problems in metallurgy because any welded component, particularly where the metal had been taken to the fusion point, presented a most complex metallurgical condition. It was one of those things which had worked and therefore one used it and now one was investigating it to find out why it worked so well. Had it been the other way round, and metallurgists had been asked to predict what such a mixed structure would do in practice, they would have hesitated to speak as confidently as they could now with the benefit of practice behind them. There was a great deal of work to be done still with each different material in assessing what the possible variation was, not only in the soundness of the weld, but in the metallurgical constitution, as well.

E. J. Catchpole (C.I.B.A. (A.R.L.) Ltd., *Associate Fellow*): He was interested to note, in reading the newspaper that morning that not all the research undertaken by Cranfield students was carried out there. One of the students had recently been awarded a £400 scholarship and had decided to spend it on a 35,000 mile tour round

the world to see what aviation conditions were like in remote areas.

Where did the bulk of the money come from for buying and operating the equipment that Cranfield had? It seemed to him that this was an important matter; for example, he had personal experience in the U.S.A. of a typical Institute of Technology which received about 85 per cent of its research money—about £1,000,000 per year—direct from industry or from the Government. He could see Professor Murphy's point that it was a good thing not to tie research too closely to industry, but if one did not do that, where *did* one get the money from? Was it, so far as this country was concerned, economical to have expensive equipment of this type without making it work directly for industry?

Another point which interested him was the position of this very excellent and special College of Aeronautics. How, again, did this relate to an Institute of Technology in which there were many other technologies represented? They talked these days in the Aircraft Industry of "diversification"; in other words, the application of their special knowledge to non-aircraft fields. On the other hand, more and more fields were taking on greater importance for aircraft applications. For example, fields such as ceramics (in which missile people were interested), chemistry (for many purposes) and atomic energy. How did the College of Aeronautics relate itself to those subjects, and should it perhaps be more diverse?

In the U.S.A. there was a considerable interchange of staff with industry. It was regarded as normal for a Professor to spend perhaps a year in industry in the middle of his academic teaching, and this seemed to be an excellent thing. What were Professor Murphy's views on this in relation to the Cranfield staff?

He was interested to hear that there was a good deal of work going on at Cranfield on optimum structures. That was a most important field on which a great deal remained to be done inasmuch as it lead to structural synthesis—how to build up a structure so as to best carry the known loads—a very time-saving operation. He felt that it would be a good thing if at some time the main Society could have a lecture on what was being done by Professor Hemp and his associates.

He felt that the research done at the College of Aeronautics (as in other institutions) was not all getting across to the Industry, although it was, of course, published in the College reports. Had Professor Murphy any suggestions as to how best to get the aircraft designers to appreciate the value of this work?

Professor Murphy: The College and its activities were financed in the main by the Government through the Ministry of Education. This applied to most of the research, but where research was sponsored by a Government Department or by a firm, then there was with that sponsoring a financial contribution which either paid for the whole of the research or made a valuable contribution to it. Whether a thing was an economic proposition depended on whether one thought one was getting value for one's money. Following on from this was the question of whether it was a good thing to refrain from soliciting more sponsored research from industry. On the whole they thought that the balance they had was not bad. He would say that there was no research going on at Cranfield which could not be seen to have a real educational content and this test they tried to apply to any research proposition that was put to them.

He believed that the Ministry of Education pursued in these matters a far-sighted and wise policy. The College had to account very carefully and strictly for how they spent the money, but he did not think they had any reason for saying that they were seriously inhibited from any justifiable activity in research or education that fell reasonably within the terms of their foundation. He should also say, of course, that they greatly appreciated the help they got from the Aircraft Industry.

There was a reference to diversification, and it was true that the boundary between what could be called aeronautical and other forms of engineering or applied science became rather shaded. Their policy was that they could see no reason against following that tendency and, in fact, this had had a natural effect in that they found themselves now offering diversified courses, mostly of a year's duration, outside their Diploma Course. They recognised that a good deal of their teaching was related to other branches of applied science or engineering than those which might be considered as limited to aeronautics.

Exchange with industry of staff—this was very easy to say and very difficult to apply *in this country*. In America and in most European countries there was a much greater flexibility and facility of exchange of technical people between industry and academic institutions. The tradition in England had never gone that way. He thought the College did pretty well, however, in achieving a similar result in a different way. They had very close contacts with industry, not only by visits from people in industry to the College and vice versa, but by the service of College academic staff on, for instance, Government Committees, alongside men from industry, and he personally felt satisfied that they missed little in this contact between members of the staff and industry. The point made on publication was very interesting indeed and in the full text of the lecture he had dealt with this to some extent. The College of Aeronautics Reports and Notes achieved good circulation among strictly aeronautical people. He believed, however, that as the process of diversification went on this would become less and less a completely satisfactory means of disseminating information about the research at Cranfield. Without in any way departing from the practice of offering their aeronautical papers to the Royal Aeronautical Society, they were going to have a look into the submission of papers to some of the other learned bodies—engineering, metallurgical, perhaps ceramic, societies.

A Speaker: Was this the first time that the British Industry had adopted the engines in and around the tail section?—and, if so, what advantage were they, other than passenger comfort?

Mr. Masefield: He could not, of course, go bail for Cranfield's designs, but there was an increasing tendency to concentrate engines in the rear of the aeroplane. The French had a great deal to be proud of in that they led the way with the Caravelle, although the Caravelle was not necessarily the very first aeroplane on which this was applied, but it was the first really successful aeroplane, and, as they knew, in the Vickers VC-10 and the VC-11 and in the DH121, in the Bristol 205 and one or two other aeroplanes, the new fashion of putting the engines at the back end had been adopted. It was a pretty good idea from a number of points of view, particularly in getting the wing really clean, for fairly high subsonic speeds; getting the engines off the wing was a very good thing indeed, apart from the fact that they were rather useful to relieve bending loads in certain aeroplanes. He thought they

would see this idea of putting engines in the rear growing more and more and there was no doubt that aerodynamically it worked well, although it had quite a lot of problems from a centre-of-gravity balance point of view, particularly as engines often grew heavier as they grew in power and therefore one had to put more length on the nose of the aeroplane to balance the fact that there were bigger and better engines. So the general tendency of the aeroplane was to grow longer and longer in front as it got more and more power at the back, and this, perhaps, was a good thing because the more capacity one put in the cabin of a civil aeroplane, the more it was able to earn money.

Professor Murphy: Was it a serious consideration that for passenger aircraft the noise was more reduced?

Mr. Masefield: It helped although there was some compressor noise in the back of the cabin.

Professor Hemp (College of Aeronautics, *Fellow*): Was it not true that as the engines got *so* much more powerful they made so much noise that they might shake the structure to pieces?

Mr. Masefield: Getting the noise away from the structure was certainly a good thing.

N. K. Benson (C.I.B.A. (A.R.L.) Ltd., *Graduate*): Could Professor Murphy say what Cranfield's attitude was to space research?

Professor Murphy: The Minister for Science had said something on this subject. They had no vaunting ambitions to send a man very far up into space. They did think, however, that it would not be unreasonable, were there a demand, for the College to offer a course in space technology. It was, after all, the gathering together of various branches of aeronautical science plus more physics and so on, and they were turning over in their minds what support there would be for, say, a twelvemonth's course of instruction in space technology.

A Speaker: Could Professor Murphy say if Cranfield were interested yet, or would be interested, in the serviceability of all those parts which went to make up a complete aircraft?

Mr. Masefield: He would say from the Chair that he hoped that Cranfield *would* be interested in this.

Professor Murphy: Was this in relation to research directed to that end?

A Speaker: Research directed towards the reliability of engines, airframe instruments and all the components on which the safety and usefulness of an aircraft depended.

Professor Murphy: He would say that as soon as the question of maintenance became amenable to a scientifically philosophical approach, then it was the affair of Cranfield and, since it was something close to his heart, he would ask Professor Whitfield to reply.

Professor Whitfield (College of Aeronautics): He thought that this was mainly a financial problem. Perhaps the worst reputation for any reliability in aircraft was that of electrical and electronic equipment. That was exactly what one would expect. Electrical equipment for aircraft was not developed.

A prototype was designed and a very small number, sometimes only one or two, were made. These were operated under unrealistically good conditions and the more obvious faults corrected. The one or two final models were run, still under unrealistically good conditions, for perhaps one thousand hours. Production models were then supplied to the aircraft firm and installed in aeroplanes. The real requirement was for reliable operation for the order of 10,000 hours, with periodic maintenance. It was not surprising that failings occurred very much more frequently. Eventually, after some years of airline operation, the reliability was raised to a reasonable level.

If equipment designers were given the facilities for a reasonable amount of ground running, under fairly severe conditions, of a number of production models, most of the design faults would be removed before use in flight. This would be expensive but not as expensive as the present practice in which aircraft were used as test beds for equipment development.

Mr. Masefield: Ninety-five per cent of civil aircraft unreliability was either electrics or hydraulics, and most of that was from components which, as Professor Whitfield had said, had not really been designed for the job. Fortunately, as the result of fifteen years of beating about since the war, a lot of the equipment was getting some semblance of reliability now. Viscounts, Comets and Britannias between them had established enough hours, something over a million and a half hours between them, to have got some components pretty reliable, and a number of aircraft manufacturers had said that, in any new aeroplane, they would have no new electrical or hydraulic components; they would only have those which had been proved in Viscounts, Comets and Britannias. This, he thought, could be a major advance in the next generation of British aircraft. The trouble was that, when it came to supersonics, they would have to have a new lot of electrics and hydraulics to stand the thermal thicket, and that was where they might be in trouble if they did not, as Professor Whitfield had said, get in 10,000 hours somehow before putting them into service. This was a matter for rigs on the ground—whether it was a Cranfield problem or not was a matter for debate.

A Speaker: Did researches at Cranfield indicate that man power would be used in flying machines?

Professor Murphy: Some effort at man powered flying trials went on at Cranfield, but those which got mentioned in the Press were not a research activity of the College of Aeronautics. They thought it was right to provide the necessary facilities for enthusiasts by way of hangarage and so on. On the subject of man powered flight in general, he would say that Cranfield's interest had taken a different course since the demonstration by Mr. Nonweiler that, according to his calculations, and from some experimental work, it was possible for two men, using a tandem cycle, to get themselves airborne and stay airborne for a period of time. Experimental work at Cranfield had not been taken farther than that at present.

A. J. Barrett (Head of Technical Department, Royal Aeronautical Society, *Associate Fellow*): Might he develop the point raised by Mr. Catchpole concerning the philosophy of American Colleges in carrying out research in separate Institutions? He thought that they had been given an unsatisfactory reason by the Lecturer and by Professor

Mair as to why British Institutions did not follow the same philosophy. The tradition of British Institutions in separating the teaching and research functions needed some examination if they wished to attract financial support for research activity. There was, he thought, an association between applied research and training as there was between fundamental research and education; from his experience of one American Institute they were sensitive to this subtlety in the United States. In deciding to undertake applied research, which was what generally attracted the big money, American colleges realised that the sponsors would not wait upon the conveniences of an academic schedule for the results. Accordingly they isolated their applied research activity in a separate organisation and left their main Institution to devote itself to training or to education and fundamental research. Fundamental research could not be carried out if it were subjected to a time scale set by a sponsor or, indeed, anyone else, but its requirements were not incompatible with those of established academic routine.

He wondered if Professor Murphy would agree that what was traditional about British Universities was that they had been concerned with *education* and that fundamental research, which was associated with this function, had been their main research activity in the past. On this basis, he would like to ask whether Cranfield intended to be a training body or an educational body and, if it were to be the latter, might they look forward to more fundamental work of the type which Professor Murphy had so interestingly described as that on materials and optimum structure?

Professor Murphy: He would not like to convey the impression that this question of the relationship between a teaching institution and research was beyond debate. There was a lot to be said on both sides. He refused to follow the suggestion of Mr. Barrett's at the end that either one was doing applied research or fundamental research and that that set one off onto one or the other of widely divergent courses. He did not believe that. He believed that the British system was best, not because it was a British system, but because if the job of an institution was primarily to teach then it must not get itself in the position when other considerations would direct the mental preoccupations of its staff. He was quite certain that in the big research institutions nominally associated with centres of learning and teaching, the people concerned with policy there became very heavily preoccupied with ensuring that next year and the year after they would have a sufficient income from sponsored research to maintain the establishment which had been built up. One saw an establishment nominally handling 30, 50, 100 graduates a year, with a staff on its research institute allegedly associated with it, numbering a thousand. Now, where was the major mental concern of the people leading that whole thing going to be? Surely it would be with making a successful " business " of the research side. This compelled them—not from any unworthy motives—to follow and adopt programmes of research which were of generally relatively short-term interest to the sponsors. Some American institutions were fortunate because the Government agency sponsoring that research took a very broad view of their responsibilities—but it was not always so. In his mind this was the major objection to building up too large a research institute in close association with a centre of teaching. He did not agree that one must deal exclusively with fundamental research or exclusively with applied research; he thought that in this country they made a sensible and satisfactory blend. This, he was satisfied, after a good deal of thought, was the right way of dealing with it.

Mr. Masefield: They were grateful to Professor Murphy for his wide exposition of Cranfield's research activities; the wide field covered was impressive. The Industry was grateful for help on the abstruse problems which from time to time were pointed in Cranfield's direction.

Research was the life blood of the Industry. It had been said that life was the art of drawing sufficient conclusions from insufficient premises and the job of research was to try to get a few of those premises more sorted out. Industry was sometimes extremely confused about these things. Walking through his Company's missile shop the other day, he noticed that an article of Embodiment Loan, a warhead of a missile on which, as Professor Murphy mentioned, some research was being done, was labelled " For the purposes of storage this warhead has to be stored with the top at the bottom and the bottom at the top. To avoid confusion, it will be seen that the top is clearly labelled " Bottom " and the bottom is clearly labelled " Top." A little research on some of the aspects of that might have been an advantage!

He wished that Professor Murphy would elimate the use of that Americanism " Dutch roll " from his descriptions. It had crept in from the U.S.A. and should be eliminated.

Professor Mair: As expected this had been a great occasion, Professor Murphy had given them much to think about. They were very grateful that he had brought his colleagues to Cambridge as well and he had much pleasure in proposing the vote of thanks.

An Investigation of Lifting Effects on the Intensity of Sonic Booms*

by

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SUMMARY: This paper is a brief summary of an investigation made to check the effect of lift on the shock noise of aircraft flying at supersonic speeds. The method of Hayes has been combined with the theory of Whitham to predict the asymptotic shock strength of wings carrying lift and of combinations of bodies and lifting wings. (A similar, but not quite as general, method was derived by Walkden in Ref. 6.) Whitham's formula, including only the volume term, has been used extensively to predict the boom intensity of aeroplane type bodies and the agreement with experiment has, so far, been quite reasonable. The test data obtained to date extends only up to about 40,000 ft. altitude and the calculations of this paper show that under those conditions the shock noise of the aircraft tested so far will, in most cases, be dominated by the volume term. It is shown that at higher altitudes lifting effects will dominate for even the small fighter and they will dominate over most of the altitude range for large bomber and supersonic transport aircraft. The boom intensity due to lift decreases with altitude as $h^{-3/4}$ which compares to $p_a^{1/2} h^{-3/4}$ in the volume case (p_a = pressure at altitude h). It is insensitive to Mach number (for $M > 1{\cdot}4$), wing loading, wing plan shape and lift distribution. A simple rule for calculating the shock noise due to combined volume and lifting effects is proposed which is applicable to configurations with wings located towards the rear of the fuselage. The rule states that the shock noise of an aircraft carrying lift is equal to the shock noise due to volume (neglecting lift) or the shock noise due to lift (neglecting volume), whichever is the greater. A chart is presented from which rapid estimates can be made of the shock noise of lifting wing-body combinations.

Introduction

The problem of shock noise associated with aircraft flying at supersonic speeds need not be emphasised here. Incidents associated with the B-58 and aircraft as small as the F104 have ensured that all agencies associated with the design and operation of supersonic aircraft recognise the seriousness of the problem.

A theory for predicting the strength of the "boom" was produced by Whitham[2]. Numerous authors have compared the predictions of Whitham's formula with experiment and the agreement is reasonable in most cases. The calculations were made assuming that lifting effects could be neglected. The experiments made so far have extended only up to about 40,000 ft. and in this range the wave drag (which is clearly related to the noise) due to lift is smaller than, or of the same order as, the wave drag due to volume. At higher altitudes, the situation is reversed and it would seem reasonable to expect the wave drag due to lift to be the largest factor in determining the shock noise.

The object of this paper is to include the lifting term in Whitham's formula, to assess its magnitude, the effect of aircraft design parameters and how it combines with the volume term.

The investigation has been limited to steady level flight conditions and the "boom" intensity is evaluated at points on the ground along the aircraft's track.

NOTATION

A_R	aspect ratio
C_R	wing root chord (ft.)
h	altitude (ft.)
K_A	attenuation factor (assumed $=(p_a/p_s)^{\frac{1}{2}}$ in this paper)
K_L	lift shape factor
K_V	volume shape factor
K_R	reflectivity factor
l	lift/foot distance along the wing centre line
l_A	length of aircraft (ft.)
l_w	length of wing (ft.)
$L(x)=l_w l(x)/W$	
p_a	pressure at altitude (lb./ft.^{2})
p_s	pressure at sea level (lb./ft.^{2})
Δp	pressure rise across shock (lb./ft.^{2})
S	wing area (ft.^{2})
S_A	aircraft cross-sectional area (ft.^{2})
S_{AM}	maximum aircraft cross section area
t	distance from nose of fuselage or wing
W	weight of aircraft (lb.)
x	distance from nose of fuselage or wing
$\mu=C_R/l_w$	
$B=(M^2-1)^{1/2}$	
$\bar{\tau}=t/l_A$	
$\overset{x}{\tau}=t/l_w$	
$\bar{x}=x/l_A$	
$\overset{x}{x}=x/l_w$	

Summary of Theory

The local flow field near an aircraft flying at supersonic speeds can be very complex and the number and location of shock waves depend on the aircraft geometry. But at large distances, the near field shocks coalesce into bow and tail shocks and the pressure signature becomes an N wave (*see* Fig. 1). The pressure rise through the front and rear shocks is the same and determined by the aircraft geometry, the Mach number

*This paper is a slightly modified version of Ref. 5.

Originally received 4th January 1960, revised 21st March 1960.

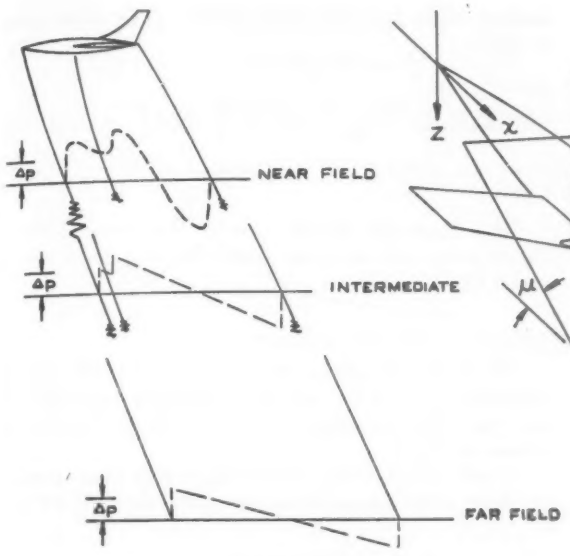

FIGURE 1. Flow field around the aircraft.

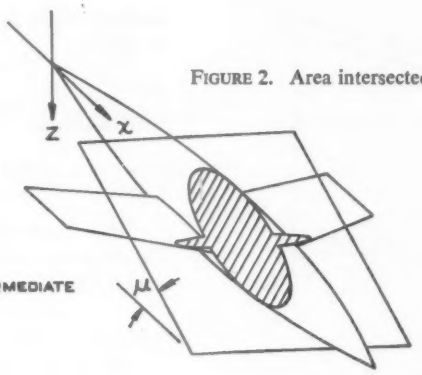

FIGURE 2. Area intersected by the Mach plane.

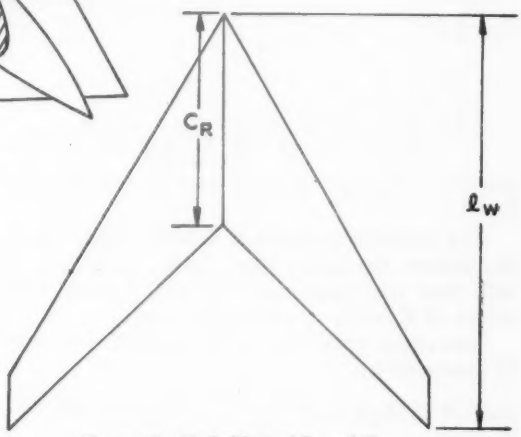

FIGURE 3. Definition of l_w and C_R.

and the distance from the aircraft (*see* Ref. 2). The human ear responds to the sudden pressure rise through the front and rear shocks and although they are close together (of the order of 0·2 sec. apart) they should be recognised as two distinct booms. For a more detailed description of the foregoing matters and the more general sonic boom problem *see* Ref. 1.

The problem then is to estimate the pressure rise through the front shock. The sudden pressure rise experienced by an observer on the ground due to a supersonic aircraft flying directly overhead at a sufficiently large altitude is given by Whitham as:

$$\Delta p = 1{\cdot}075 K_B K_A (M^2-1)^{1/8} \left[\int_0^{x_0} F(x)\,dx \right]^{1/2} h^{-3/4} p_e. \quad (1)$$

The limit of integration x_0 depends on the properties of $F(x)$ (*see* Ref. 2) and $F(x)$ is a function depending on the geometry of the aircraft and lift carried. If lift is neglected and the configuration is slender

$$F(x) = \frac{1}{2\pi} \int_0^x \frac{S_A''(t)\,dt}{(x-t)^{1/2}}$$

where S_A'' is the second derivative of the aircraft (*i.e.* fuselage + wing + tail, etc.) normal cross-sectional area with respect to "t", the distance from the nose of the fuselage. To be more exact, the area S_A should be the area intercepted by the Mach plane $X = x + Bz$ projected along the flight direction (*see* Fig. 2) *i.e.* if the area intercepted obliquely is $s(x)$ then

$$S_A(x) = s(x) \sin \mu$$

where μ is the Mach angle. The procedure is exactly the same as in the supersonic area rule[4], but if the body is slender and the wing height above the body centre line is small compared to the fuselage length, it is sufficient to take normal cuts (*i.e.* a Mach 1·0 area plot).

It can be shown by the method of Ref. 3 that the effect of a lifting wing at large distances directly below the wing is the same as a body of revolution whose area distribution is given by:

$$S_L'(x) = \frac{Bl(x)}{2q}$$

where $l(x)$ is the lift/foot distance along the wing centre line

$$B = (M^2-1)^{1/2}, \qquad q = 1/2\rho V^2.$$

The $F(x)$ function, including lift and volume, is then

$$F(x) = \int_0^x \left[\frac{S_A''(t)}{2\pi} + \frac{Bl'(t)}{4\pi q} \right] (x-t)^{-1/2} dt. \quad (2)$$

A clearer picture of the major variables that affect the shock noise is obtained if the $F(x)$ function is made non-dimensional. The shock noise due to volume (*i.e.* lift neglected) can then be expressed as follows:

$$\Delta p_V = 0{\cdot}429 K_B K_A K_V (M^2-1)^{1/8} \frac{S_{AM}^{1/2}}{l_A^{1/4}} h^{-3/4} \quad . \quad (3)$$

where S_{AM} maximum aircraft normal cross-sectional area
l_A length of aircraft (ft.)
K_V volume shape factor

$$= \left[\int_0^{\bar{x}_V} \int_0^{\bar{x}} \frac{S_A''(t)}{(x-t)^{1/2}} d\tau d\bar{x} \right]^{1/2}$$

and $\bar{x}_V$ corresponds to the x_0 of equation (1) for the special case where lift is neglected. K_V depends only on the shape of the body and not on its length or fineness ratio.

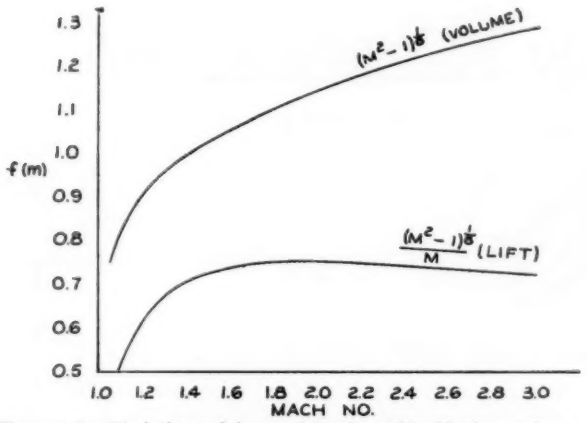

FIGURE 4. Variation of boom intensity with Mach number.

For practical supersonic aircraft shapes K_V should lie between the approximate limits 1·5 to 2·0. Bodies with their maximum thickness well forward will have values of K_V closer to the upper limit.

The shock noise due to lift (neglecting volume) can be expressed as:

$$\Delta p_L = 0{\cdot}363 K_R K_A K_L \frac{(M^2-1)^{3/8}}{M} \frac{W^{1/2}}{l_w^{1/4}} p_a^{-1/2} h^{-3/4}. \quad (4)$$

The lift shape factor $K_L = \left[\int_0^{\bar{x}_L} \int_0^{\bar{x}} \frac{L'(\bar{\tau})}{(\bar{x}-\bar{\tau})^{1/2}} d\bar{\tau} d\bar{x} \right]^{1/2}$

and $\int_0^1 L(\bar{\tau})\, d\bar{\tau} = 1{\cdot}0.$

x_L corresponds to the x_2 of equation (1) for the special case where volume is neglected. The range over which K_L varies in practice seems to be between 1·4 and 1·63.

Equation (4) may be written in a more interesting form if we confine the wing to have straight leading and trailing edges and zero taper ratio. The shock noise is then

$$\Delta p_L = 0{\cdot}305 K_R K_A K_L \frac{(M^2-1)^{3/8}}{M} W^{3/8} \left(\frac{W}{S} A_R \mu^2 \right)^{1/8} p_a^{-1/2} h^{-3/4} p_t \quad . \quad . \quad (5)$$

where $\mu = C_R / l_w$.

This equation shows clearly that wing loading, aspect ratio and the plan shape factor μ have only a minor effect on Δp_L.

Effect of Mach Number

Mach number affects the "volume" and "lift" booms differently as can be seen by comparing equations (3) and (4). The variation of the two Mach functions is shown in Fig. 4.

It will be noted that the variation with Mach number of shock noise due to lift is very small above $M = 1{\cdot}4$.

"Volume" Boom Intensity

For many practical cases, as will be shown later, lift has a small or zero effect on the shock noise. The "boom" intensity can then be estimated by equation (3) which neglects lift and this equation is shown plotted in Fig. 5 for a range of $(M^2-1)^{1/8} S_{AM}^{1/2} l_A^{-1/4}$ from 1·0 to 4·0 and a reflectivity factor $K_R = 2{\cdot}0$. An auxiliary scale of decibels (peak pressure) is shown at the right of the figure and also shown are the corresponding physical and physiological reaction (abstracted from N.A.C.A. Memo 3-4-59L) to the "boom" pressure rise.

The figure shows that aircraft with large cross-sectional areas will have to accelerate to supersonic speeds at fairly high altitudes if damage to plate glass windows is to be avoided. *If* the shock noise is determined by volume at cruise altitudes, it would probably be in the "tolerable" range.

A volume factor K_V of 1·75 was assumed in constructing Fig. 5. The results can easily be corrected to any other volume factor by multiplying the pressures in the figure by $K_V/1{\cdot}75$. The variation of K_V with the location of the fuselage maximum cross-sectional area is shown in Fig. 6 (data abstracted from Ref. 1). The evaluation of K_V for practical aircraft shapes is rather tedious, but in the author's experience $K_V = 1{\cdot}9$ is usually within a few per cent of the right answer.

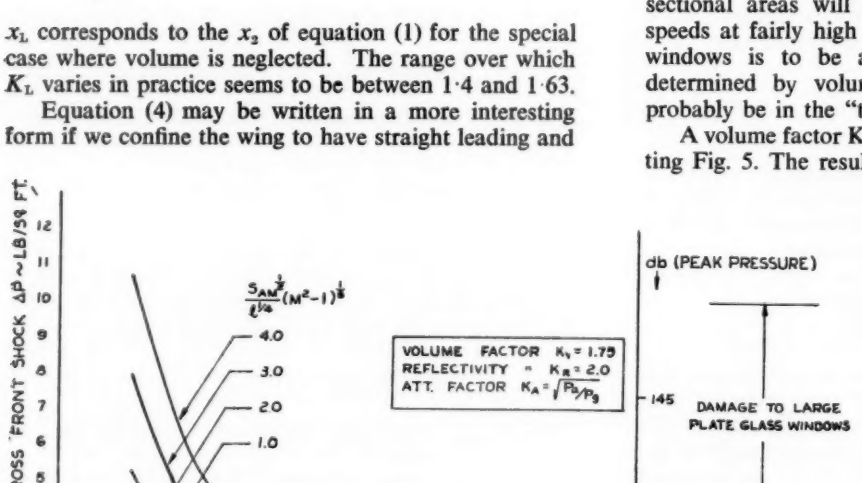

FIGURE 5. Boom intensity due to volume.

"Lift" Boom Intensity

The pressure rise on the ground due to lift is given by equation (5) for wings with straight leading and trailing edges. This equation is plotted in Fig. 7 for a range of aircraft

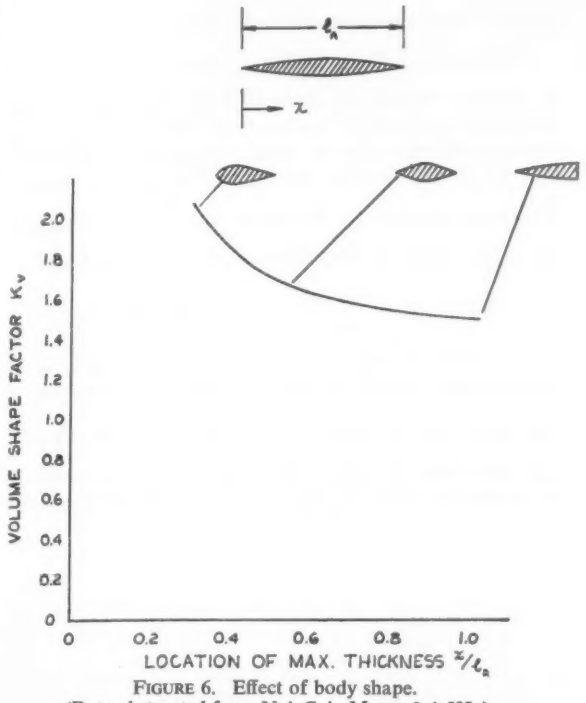

FIGURE 6. Effect of body shape.
(Data abstracted from N.A.C.A. Memo 3-4-59L.)

weights from 25,000 lb. to 600,000 lb., $(W/SA_R\mu^2)$ from 50 to 150 and a reflectivity factor $K_R=2{\cdot}0$.

A lift shape factor K_L of 1·63 (corresponding to a flat delta wing) was used in constructing Fig. 6 and the results may easily be scaled to any other lift factor by multiplying by $K_L/1{\cdot}63$.

If the shock noise is dominated by lifting effects, the heavier aircraft will have to accelerate to supersonic speeds at the highest possible altitude to minimise community reaction and damage to windows: at cruise conditions the noise will always be in the "objectionable" range.

The effects of the longitudinal lift distribution appear through the lift shape factor K_L and this factor has been

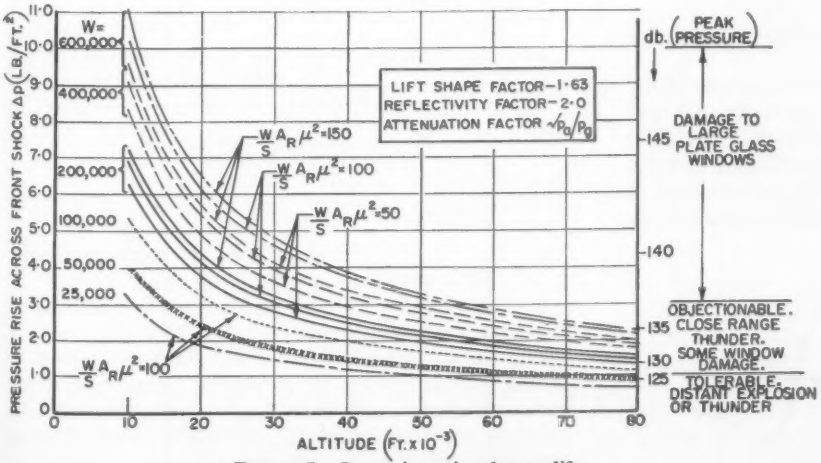

FIGURE 7. Boom intensity due to lift.

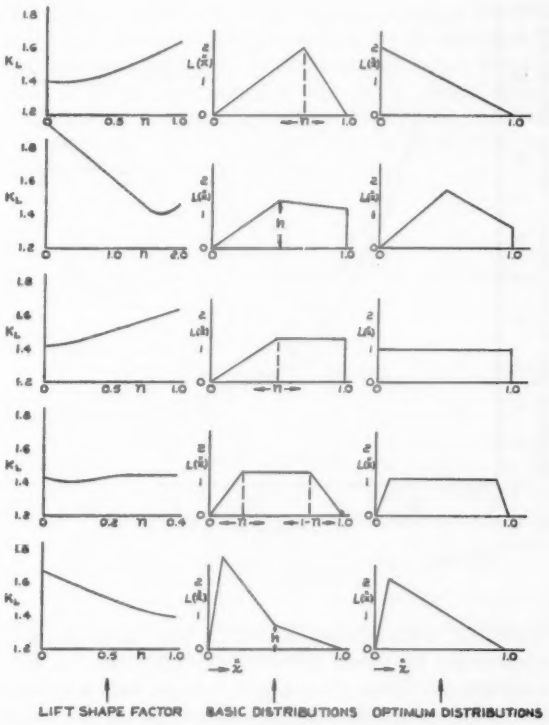

FIGURE 8. Effect of longitudinal lift distribution on lift shape factor K_L.

computed for a variety of lift distributions. For each basic distribution a single factor such as the longitudinal location of the maximum lift per ft. was varied. The results are given in Fig. 8 which shows the basic distributions assumed, the parameter varied, the variation of K_L and the optimum distributions. It will be noted that a wide variety of distributions give a minimum value of $K_L \simeq 1{\cdot}4$.

Boom Intensity Due to Combined Lift and Volume

An example is presented in Fig. 9 of the boom intensity as a function of altitude for a delta wing-body combination consisting of a parabolic body ($l_A=100$ ft., $S_{AM}=100$ ft.²) and a wing ($l_w=50$ ft.) of zero thickness carrying 150,000 lb. of lift. The effect of varying the wing location along the body is also shown.

With the wing in the forward position, the boom pressure rise is appreciably greater than either the volume or lift boom pressure at all altitudes. The boom pressures of the configuration with the wing at the rear of the body agree exactly with the volume boom pressures at altitude below

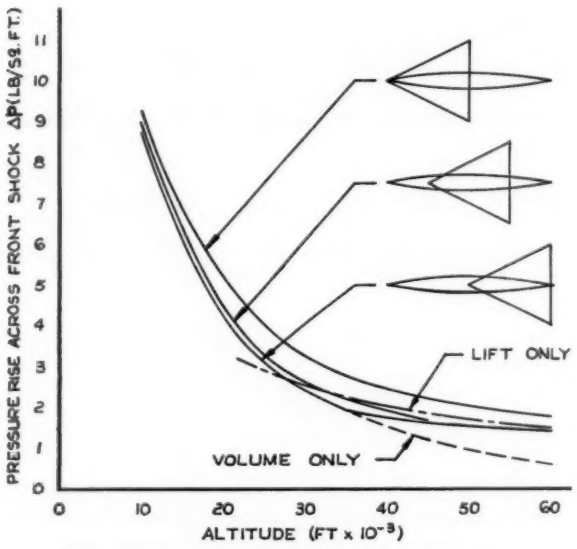

FIGURE 9. Boom intensity due to a lifting wing-body combination ($M=1{\cdot}5$).

30,000 ft.; while above 30,000 ft. they have the same trend as the lift boom pressures although they are somewhat lower. When the wing is located half way along the body, the results are very similar to the aft located wing-body configuration.

The reasons for the variation of boom intensity with wing location and altitude are not difficult to understand providing we know how to interpret the integral $\int_0^{x_0} F(x)\,dx$. A detailed discussion of this is beyond the scope of this paper and the reader is referred to Whitham's classic paper[2] for complete details. However, without going into the reasons why, it can be stated that the choice of the upper limit of integration x_0 must be such that the integral $\int_0^{x_0} F(x)\,dx$ is maximised.

To illustrate this, a typical $F(x)$ curve is shown in Fig. 10 where it will be assumed, for the sake of argument, that the curve does not re-cross the x-axis to the right of x_{00}. Then if area C is less than area B the upper limit of integration $x_0=x_0$ but if area C is bigger than area B $x_0=x_{00}$.

The $F(x)$ functions of the parabolic body and lifting delta wing of zero thickness used as examples in Fig. 9 are shown in Figs. 11(*a*) and (*b*) respectively. The $F(x)$ function of the wing is shown for two altitudes with the wing in the aft position, it is inversely proportional to the ambient pressure p_a due to the q term in equation (2).

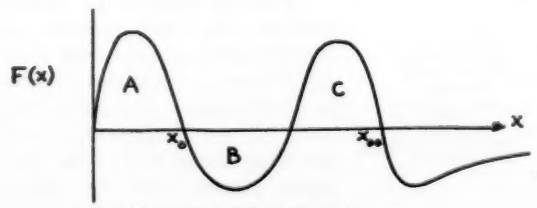

FIGURE 10. Typical $F(x)$ curve.

The $F(x)$ for combined lift and volume:

$F(x)_{\text{combined}}=F(x)_{\text{vol}}+F(x)_{\text{lift}}$ from equation (2)

so that by adding the $F(x)$ of Figs. 11(*a*) and (*b*) we obtain the combined $F(x)$ functions shown in Figs. 11(*c*) and (*d*). If the lift is zero $F(x)_{\text{combined}}$ is given by Fig. 11(*a*) and in this case area $C <$ area B (from a condition deduced by Whitham that $\int_0^{\infty} F(x)\,dx=0$) and the upper limit of integration $x_0=x_0$. The integral

$$\int_0^{x} F(x)\,dx=\frac{1{\cdot}45S_{AM}}{\pi l_A^{1/2}} \quad \text{for a parabolic body.}$$

At 10,000 ft. the area C is still less than area B for the example chosen so that the limit of integration x_0 and hence the $\int_0^{x_0} F(x)\,dx$ is the same as in zero lift case. Lift then does not affect the boom intensity at 10,000 ft. At 60,000 ft. area C is greater than area B and $x_0=l_A$ and

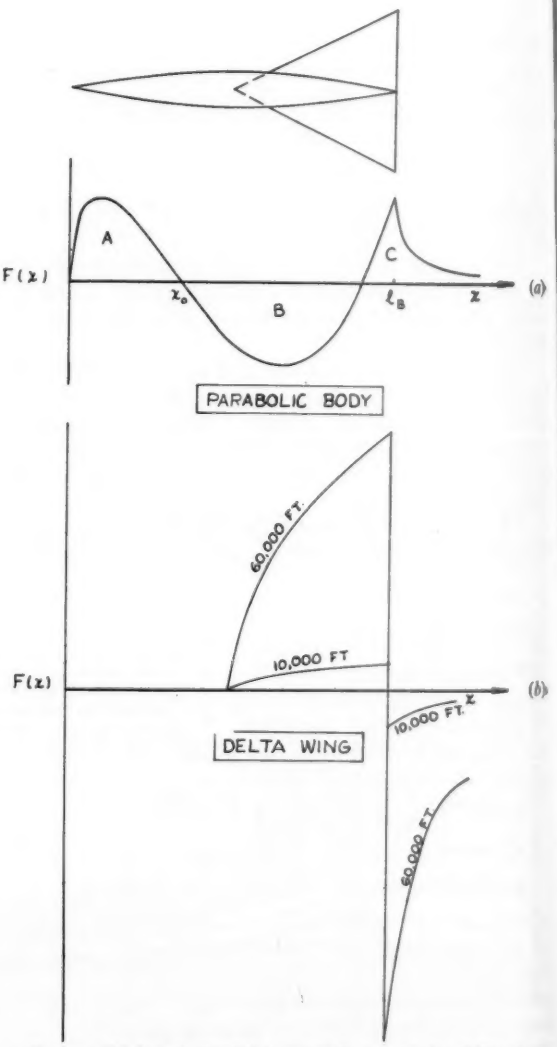

FIGURE 11(*a*) and (*b*). $F(x)$ curves for example of Fig. 9.

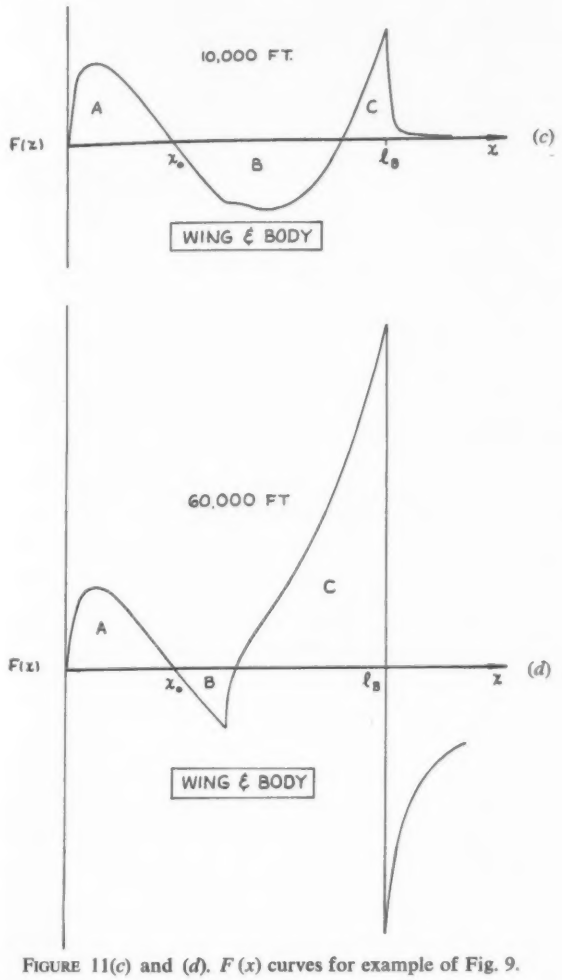

FIGURE 11(*c*) and (*d*). $F(x)$ curves for example of Fig. 9.

lift now contributes to the boom intensity. It is a relatively simple matter to show that

$$\int_0^{l_A} F(x)\,dx = \frac{2^2 2^{1/2} BW}{3\pi\gamma p_s M^2 l_A^{1/2}} - \frac{0{\cdot}61 S_{AM}}{\pi l_A^{1/2}}$$

for this example providing area $C >$ area B.
The boom intensity then is

$$\Delta p_1 \propto \left[\frac{1{\cdot}45 S_{AM}}{\pi l_A^{1/2}}\right]^{1/2} \quad . \quad . \quad . \quad (6a)$$

or

$$\Delta p_2 \propto \left[\frac{2^2 2^{1/2} BW}{3\pi\gamma p_s M^2 l_A^{1/2}} - \frac{0{\cdot}61 S_{AM}}{\pi l_A^{1/2}}\right]^{1/2} (6b)$$

whichever is the greater.

The Δp curves for the other examples of Fig. 9 can be derived in a similar manner.

When the wing is in the rear position it is clear, from equations (6*a*) and (6*b*) that there is a value of the ambient pressure (which is, of course, a function of altitude) where $\Delta p_1 = \Delta p_2$; below this altitude the boom intensity is not affected by lift, while above this altitude, according to equation (6*b*), the shape of the body and the amount of lift the wing carries determine the boom intensity. However, for altitudes at which equation (6*b*) applies, the lifting term is considerably larger than that due to body shape and if the body shape term is neglected, the maximum error incurred is 16 per cent for this example. The boom intensity is then given to a reasonable degree of approximation by

$$\Delta p_1 = A\left[\frac{1{\cdot}45 S_{AM}}{\pi l_A^{1/2}}\right]^{1/2} = \Delta p_V$$

i.e. the boom due to volume only

$$\Delta p_2 = A\left[\frac{2^2 2^{1/2} BW}{3\pi\gamma p_s M^2 l_A^{1/2}}\right]^{1/2} = \Delta p_L$$

i.e. the boom due to lift only

whichever is the greater. $(A = 1{\cdot}075 K_A K_R (M^2-1)^{1/8} p_E)$.

It has been noted in a number of other examples computed by the author that when the wing is located towards the rear of the body the shock noise at low altitudes can be computed quite accurately by neglecting lift while at high altitudes it is given to a reasonable degree of accuracy by neglecting the volume.

The following simple rule is therefore tentatively suggested to obtain an approximate estimate of the shock noise of such configurations.

$\Delta p_{\text{combined}} = \Delta p_V$ or Δp_L whichever is the greater.

This rule should be applicable to most supersonic aircraft flying today and those projected.

In view of the fact that the evaluation of the integral

$$F(x) = \int_0^x \left[\frac{S_A''(t)}{2\pi} + \frac{l'(t)\,B}{4\pi q}\right](x-t)^{-1/2}\,dt$$

is very tedious for practical wing-body combinations; it is convenient to have such a simple rule available.

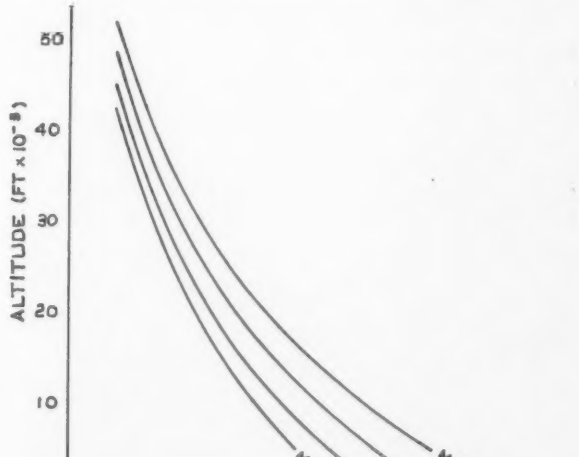

FIGURE 12. Approximate altitude above which lift dominates boom intensity.

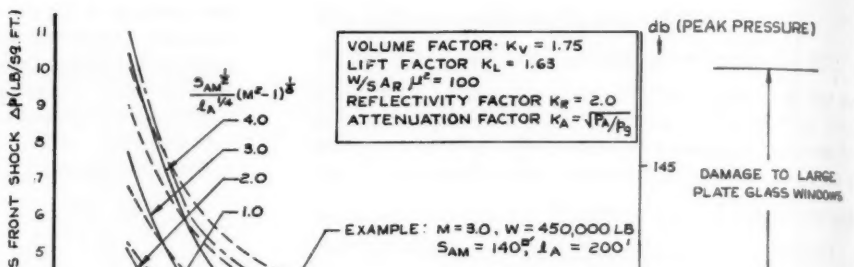

FIGURE 13. Boom intensity of lifting wing-body combinations (applicable to configurations with aft located wings).

The physical reason why the wing lift does not affect the boom intensity of rear winged configurations at low altitudes is due to the fact that the negative pressures over the rear of the body cancel the positive pressures generated by the wing lift. At higher altitudes the lifting pressures become strong enough to force the way through the negative pressure field of the body and influence the strength of the front shock in the far field.

By using the simple rule, it is possible to obtain a rough estimate of the altitude above which the shock noise is lift dominated. If we equate equations (3) and (4), we can solve for the ambient pressure at which the volume boom is equal to the lift boom. We get:

$$p_{crit} = 0{\cdot}716 \left(\frac{K_L}{K_V}\right)^2 \frac{(M^2-1)^{1/2}}{M^2} \left(\frac{l_A}{l_w}\right)^{1/2} \frac{W}{S_{AM}} .$$

This equation is shown plotted in Fig. 12 for a Mach number range from 1·5 to 3·0. (Instead of the ambient pressure p_{crit} the altitude h_{crit} has been used.)

The following typical examples are presented with $l_A/l_W = 2{\cdot}0$, $(K_L/K_V)^2 = 0{\cdot}9$ and $M = 2{\cdot}5$.

(*i*) *Fighter*
$W = 15{,}000$ lb. $S_{AM} = 20$ ft.^{2} $h_{crit} = 49{,}000$ ft.

(*ii*) *Light Bomber*
$W = 150{,}000$ lb. $S_{AM} = 100$ ft.^{2} $h_{crit} = 35{,}000$ ft.

(*iii*) *Heavy Bomber*
$W = 400{,}000$ lb. $S_{AM} = 100$ ft.^{2} $h_{crit} = 12{,}000$ ft.

At lower Mach numbers the altitudes would decrease.

It appears that the shock noise of heavy bomber and transport configurations will be dictated by lifting effects over most of the altitude range.

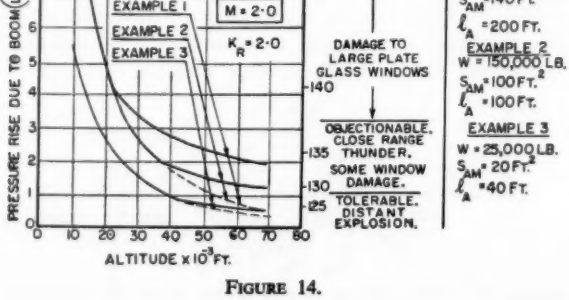

FIGURE 14.

A combined graph (Fig. 13) has been constructed using the volume boom curves of Fig. 5 and the approximate formula for the lift boom. A quick estimate of the shock noise of configurations with wings located at the rear of the body can be made using the graph. An example is shown.

Conclusions

The calculations of this paper show that lift has a greater effect on shock noise than had previously been assumed. Lift will dominate the shock noise of most aircraft at high altitudes and over most of the altitude range for large aircraft.

The shock noise at cruise altitudes due to aircraft weighing more than about 150,000 lb. will be in the "objectionable" range and minor glass damage may occur.

To put the above conclusions into perspective, the shock noise of three aircraft, differing widely in weight and size has been estimated (using Fig. 12) and compared in Fig. 14. It will be noted that the shock noise at cruise altitudes of the two heavier aeroplanes will be in the range termed "objectionable."

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Power Plants for Supersonic Transports*

by

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Introduction

The honour that has been accorded me in being invited to deliver the Second Halford Lecture is very much appreciated. My personal acquaintance with Major Halford began about fifteen years ago, and every step since has been one of increasing respect and esteem. It is a privilege and pleasure to pay tribute to the memory of a man whom I recall as an effective crusader for simplicity and reliability in engine design. In the First Lecture[1], John Brodie discussed very fully the contribution of Major Halford to aircraft power plants, and little is left for subsequent lectures on this subject. I have therefore chosen to speak on the propulsion problems of high-speed aircraft—a field of primary interest to Halford, as demonstrated by the outstanding success of the Goblin and Ghost engines, and more recently by the Gyron series designed for supersonic propulsion.

Commercial transport development has traditionally followed Military research and development. The background for a supersonic transport has now been provided by the development of a series of air weapons operating at a Mach number of 2 and above. Broadly speaking, it seems to me that any study of power plants for supersonic transports should first review technology and progress in areas where experience has been obtained, or design effort is under way. I propose in what follows to discuss some aspects of my own experience with General Electric in these areas under different headings.

The J79 Turbo-jet Family

The basic problem of low-speed stall in high-pressure-ratio jet engines has several solutions. The variable-stator principle had been demonstrated on a compressor component test, and the decision was made to utilise this in the new engine. Major Halford visited us at the time when various alternatives were being studied as a preliminary to selecting the best engine. As I recall, he was keen in seeing us try the variable-stator approach. Were he here today, I think he would be interested to know that J79-powered aircraft have flown more than three-fourth's of the free world's time at a Mach number of 2 and above. A side view of the J79-5 turbo-jet, as used in the Convair Hustler, is shown in Fig. 1 and I will describe briefly some of its more interesting features.

COMPRESSOR

The compressor is a seventeen-stage, 12·8 : 1 pressure ratio, single rotor, axial flow type with the first six stator stages variable. The compressor rotor and casing are shown in Fig. 2. The variable-stator mechanism operates rapidly to provide the desired stator setting at each r.p.m. The J79-2, as used in the McDonnell F4H Phantom II, and the North American A3J Vigilante has an acceleration time of 2·5 seconds from idle at 67 per cent of rated r.p.m. to maximum non-augmented thrust. With 9·5 per cent air extraction from the compressor discharge, the time to accelerate from idle to maximum non-augmented thrust is between five and six seconds.

A record of excellent compatibility with the induction systems of all installations has established the J79 as outstanding in its ability to tolerate inflow distortion. The installations include six air weapons operating at Mach 2·0 and above. Low aerodynamic loading in the front compressor stages contributes to this tolerance. Adverse inlet conditions occurring at high supersonic flight speeds and corresponding intermediate engine r.p.m. can be accepted by adjusting the variable stators at the expense of a moderate reduction of air flow and thrust. For example, a problem of engine stall during gun firing was solved through the flexibility and fast action of the variable stators.

Gun gases, which accumulate at a phenomenal rate because of the very rapid firing, are swept into the inlet. The extremely rapid change in inlet temperature and pressure caused transient mismatching in the compressor and resulting stall. As a possible contributing factor, a total temperature distortion of 70°F was measured at the compressor face.

Many schemes of diverting the gun gases away from the inlet were tried and discarded. The solution was to provide a gun gas "twitcher" which closes the stators 5° when the gun is being fired.

Induction system flow instability known as "buzz" has been encountered at Mach 2 and above. As regards structural integrity, experience indicates that if a jet engine can withstand repeated stalls at sea level static conditions, the engine will be able to withstand inlet buzz and stall at Mach 2 at the altitudes flown by existing operational aircraft.

THIN WALL CONICAL SHAFT

The general construction of the engine is shown in Fig. 3. A thin-wall conical shaft is used to transmit the turbine torque to the compressor rotor drive spline. The design intent is to expose the largest possible area of wheel, shaft, and interstage structure to the internal cooling air, and to confine the stream of hot gases to the gas passage. The internal cooling air flow is not diluted by admixture with hot gases. This feature is particularly desirable at high supersonic speeds where the initial temperature of the cooling air is high.

It will be seen that the cooling air for the turbine is extracted through holes in the spacer located between the seventh and eighth stages of the compressor. A radial

*The Second Halford Lecture—given before the Hatfield Branch of the Society on 11th May 1960.

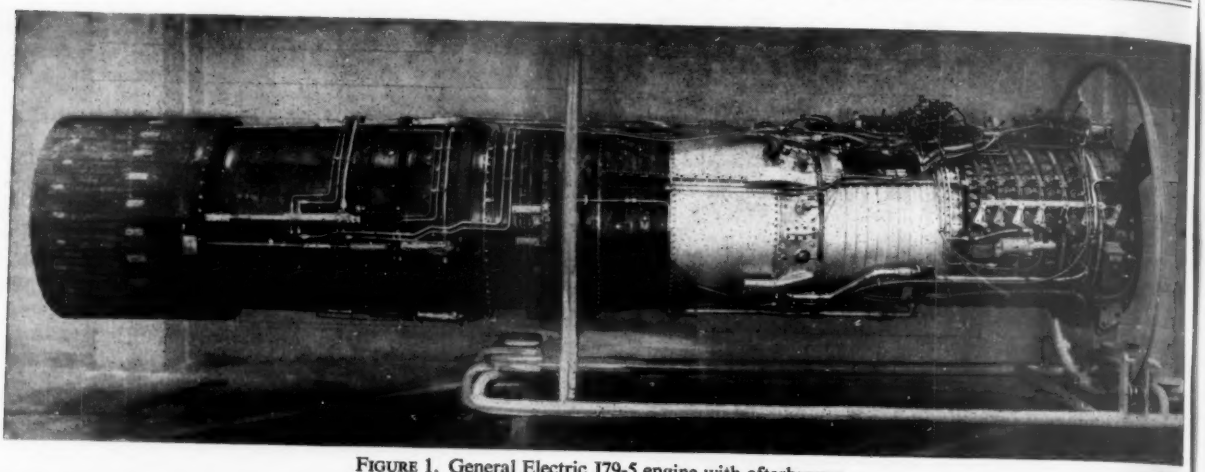


FIGURE 1. General Electric J79-5 engine with afterburner.

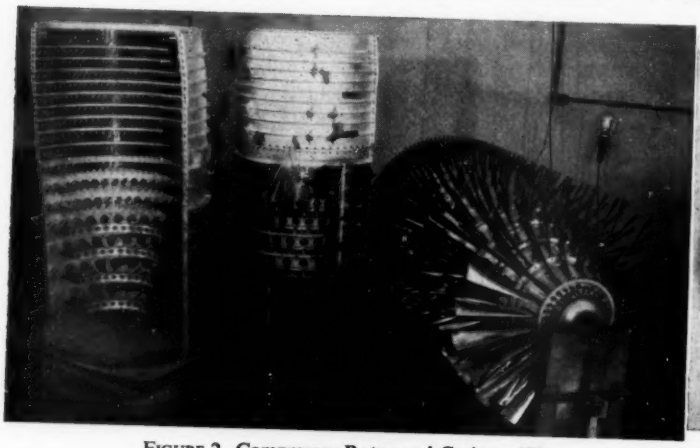


FIGURE 2. Compressor Rotor and Casing—J79.

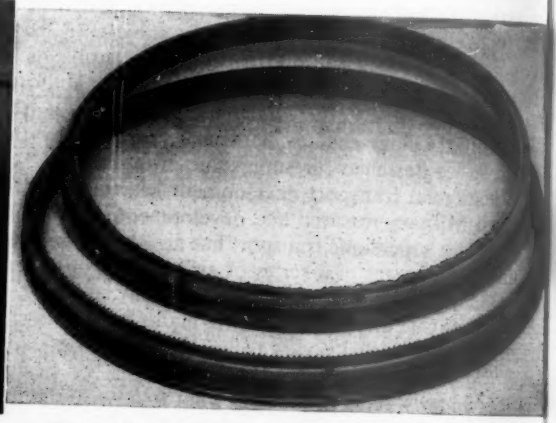


FIGURE 5. Honeycomb Turbine Seals after 4,084 Hours.

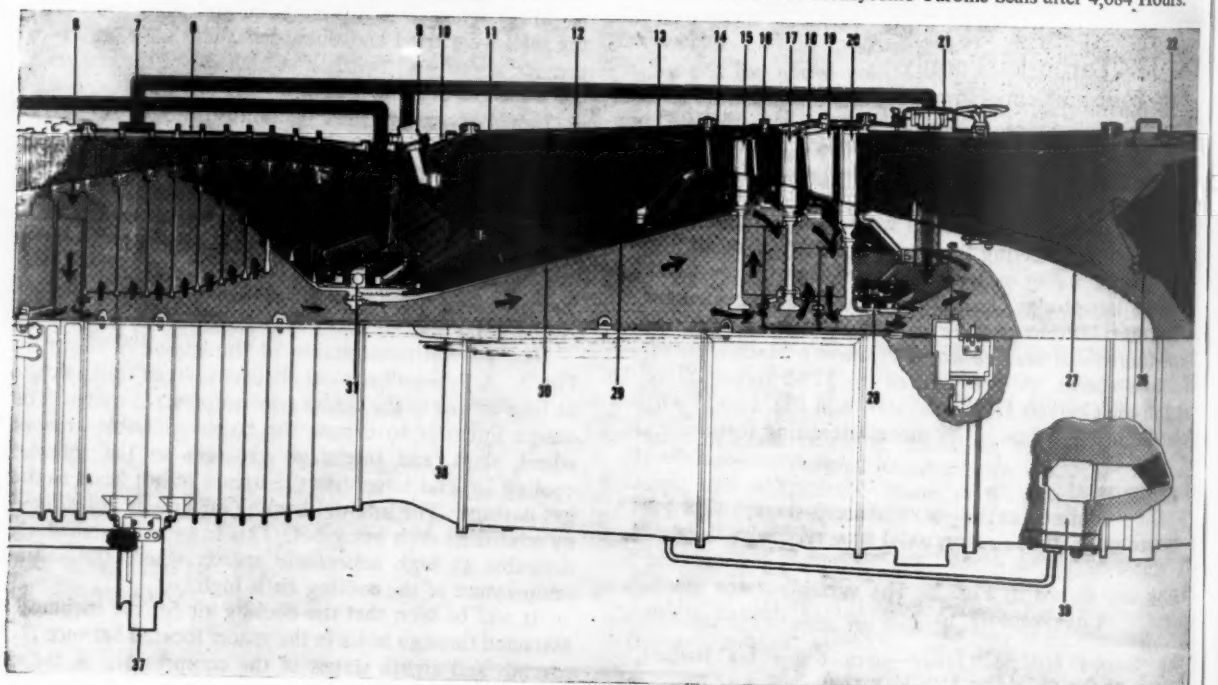


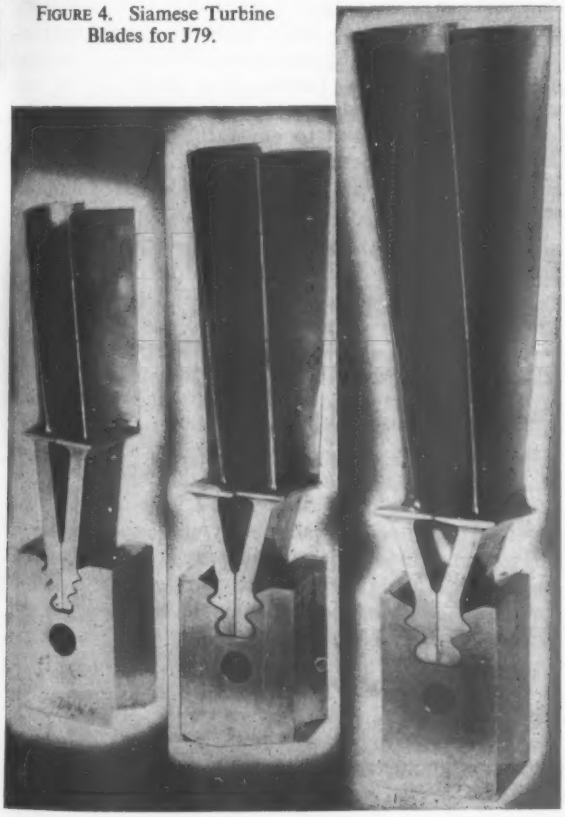
FIGURE 3. Internal Air Flow Diagram—J79.

baffle is provided between the adjacent discs on each side of the air extraction openings so that the internal cooling system is of the forced vortex type. After flowing aft through the hollow shaft, the cooling air is pumped out to the rim by four equi-spaced baffles mounted on a metal disc located between the first and second stage turbine wheels. After cooling the rims and the torque ring which connects these two disc wheels, the cooling air again flows inward guided by radial baffles which remove angular momentum and make the flow field approximate a forced vortex. The cooling air then flows through a similar path between the second and third stage turbine discs.

THE TWIN OR SIAMESE BUCKET SHANK AND DOVETAIL

The twin shank and dovetail fastening is shown in Fig. 4. Each individual blade is displaced from a radial line, and the centrifugal field produces pressure at the mating faces of a bucket set. The twin or Siamese bucket shank and dovetail operate satisfactorily at gas bending loads which resulted in fatigue failures when conventional single buckets were used. Analysis and experiments show the friction damping between mating surfaces of a bucket pair to be effective in reducing vibratory stresses. Strain-gauge measurements confirm that for the resonant condition when the bucket frequency is an integral multiple of engine speed, the measured vibratory stress in a Siamese bucket peaks at roughly half the stress recorded in a normal undamped single bucket.

FIGURE 4. Siamese Turbine Blades for J79.



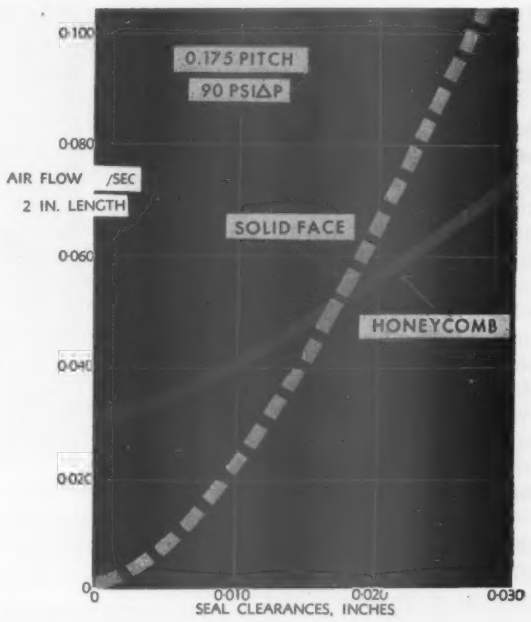


FIGURE 6. Comparative Leakage Rates—Honeycomb and Normal Labyrinth Seals.

HONEYCOMB SHROUDS

Honeycomb shrouds adjacent to the bucket tips are used to achieve minimum bucket tip clearance. The rubbing surface permits bucket tip clearance as low as 0·008 inch minimum compared to 0·040 inch minimum for a non-rubbing sheet metal shroud. Turbine efficiency was improved 1·2 per cent overall in the J79 engine by the use of honeycomb shrouds alone.

Open-face honeycomb seals are also used to control turbine interstage gas leakage and have functioned well over long periods of operation. Fig. 5 shows a pair of honeycomb interstage seals which have accumulated over 4,000 hours of running. A honeycomb surface reduces the metal in contact during a rub by a factor of about 10 to 1, and allows reduction in seal clearance to the point that a 100 per cent seal rub can be safely accepted. A comparison of the air leakage of honeycomb-faced and flat-faced normal labyrinth/straight tooth seals is shown in Fig. 6. It will be seen that for clearances greater than about 0·020 inch, the honeycomb-faced seal has less leakage than the smooth-faced seal.

Installation Co-ordination

In supersonic applications, there is a very close relationship between the induction system, the secondary air system, the jet nozzle, and the basic engine.

We in General Electric believe that the success of the installed propulsion system on the Convair B-58 Hustler (Fig. 7) owes a great deal to what has been one of the most cordial and rewarding technical relationships ever achieved between aircraft and engine manufacturers. Mr. R. J. Patton has been the mainspring on the Convair side, and his outstanding contributions and leadership are gratefully acknowledged.

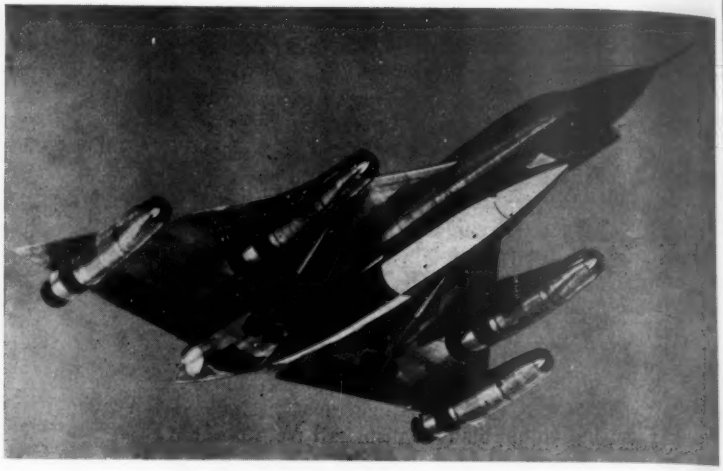


FIGURE 7. Convair B-58 Hustler—Supersonic Bomber.

Initial flights to evaluate the acceleration and supersonic cruise characteristics showed that above a Mach number of 1·5, the time to accelerate and the fuel consumed increased rapidly. The changes initiated and sponsored by a performance committee set up by the two firms reduced the acceleration time from subsonic cruise to Mach 2·0 by one-half, and substantially improved the subsonic range. These changes consisted of a redesigned nose cowl—permitting greater air flow to engine—and a revised main fuel control giving the pilot option of increasing the engine r.p.m. to 103·5 per cent while at maximum reheat power setting.

Inflow distortion may be responsible for any one or all of four problems: compressor stall, reduction in air flow and compressor efficiency, high blade stresses and hot spots at the turbine inlet.

The effect of circumferential variation in total pressure on engine stall limits is shown on Fig. 8. The ordinate is the per cent corrected r.p.m. at which compressor stall occurs. The abscissa is the distortion index N_c. This index is the product of two factors, the first of which is simply the difference between the maximum and minimum total pressure divided by the average absolute total pressure at the compressor face. The second factor is a function of pattern and has a maximum value of one for the most severe type of pattern. This most severe pattern is where a deficiency in total pressure occurs in a single large area covering one-half of the circumference. Figures on the curves are values of Reynolds Number Index, which is the ratio of the compressor inlet Reynolds number at a specific flight condition to the Reynolds number which would exist at the same corrected r.p.m. if the compressor inlet were at standard sea level static conditions.

The lower set of curves of Fig. 8 define the low speed stall limit for fixed positions of the variable stators. The low corrected r.p.m. stall is relatively insensitive to circumferential variations of total pressure provided the circumferential distortion index does not exceed approximately 7 per cent.

The upper set of curves define the high speed stall limit. The high corrected r.p.m. stall is also relatively insensitive to circumferential variations of total pressure, provided the distortion index does not exceed approximately 10 per cent. By providing an analytical method of evaluating inflow pattern (*see* Refs. 2–10), use of the distortion index saves some expensive engine testing previously used to cover the large number of inflow patterns generated by variation in such parameters as flight Mach number, angle of attack, inlet mass flow ratio, position of variable geometry inlet, yaw, etc.

The effects of inlet distortion upon the compressor air flow were evaluated from B-58 inlet distortion patterns measured during wind tunnel tests. These analyses showed that for the normal subsonic cruise condition, the air flow would be reduced by not more than one per cent and that, at a constant engine speed, the SFC was not affected by the inflow distortion level.

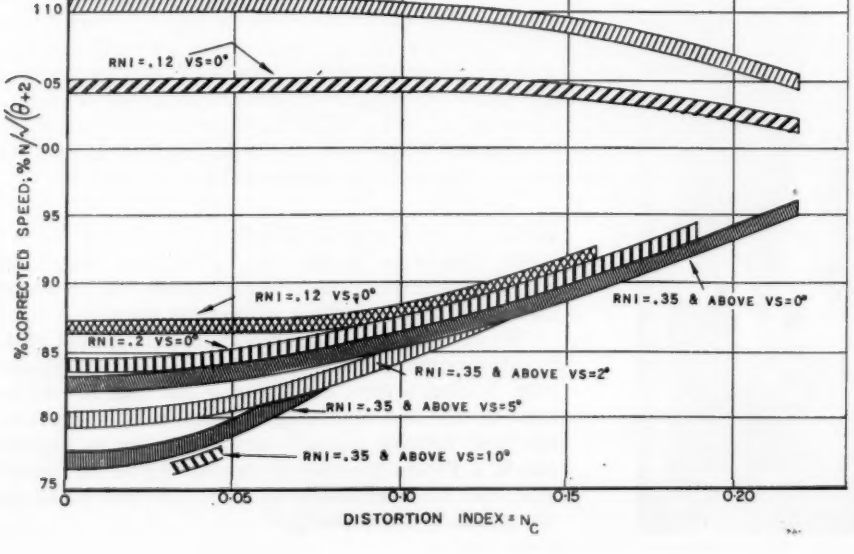


FIGURE 8. Effect of Inflow Distortion on Engine Stall Limits.

VARIABLE CONVERGING-DIVERGING EXHAUST NOZZLE

Because of the vital importance of converging-diverging exhaust nozzles to supersonic aircraft, recent progress will be described in some detail. Thrust augmentation by exhaust reheat has been utilised for substantially all supersonic flight. However, since the majority of the B-58 mission is accomplished at subsonic speeds, the non-augmented cruise thrust and specific fuel consumption are very critical. The requirement was for the variable nozzle to have relatively little divergence for subsonic cruise and to become a converging-diverging nozzle at high nozzle pressure ratios occurring at supersonic speeds.

The Ejector Nozzle

The variable converging-diverging exhaust nozzle first developed for supersonic aircraft utilised secondary air flow to control the supersonic expansion of the primary stream, and is known as the ejector nozzle. When closed in the subsonic cruise position, the ejector nozzle has a 28° boat-tail angle.

Base drag of jet nozzles has not been a serious problem in fuselage installations where the maximum frontal area of the fuselage is much larger than the nozzle area. The smooth ellipsoidal shape of typical fuselage afterbodies reduces the external local velocity and so tends to increase the local static pressure upstream of the jet nozzle.

Low Base Drag Nozzle

During the early development of the B-58, experimental studies by N.A.C.A. showed that the 28° boat-tail angle of the J79 ejector nozzle, in nacelles similar to those of the B-58, produced severe base drag penalties at subsonic flight conditions. Convair and General Electric initiated a programme to develop a new nozzle, which became known as the "Low Base Drag Nozzle" (LBDN). The goals of the new design were twofold:

(*i*) Reduction in nacelle-nozzle drag, primarily through reduced boat-tail angle.

(*ii*) Improvement in the internal performance during non-reheat subsonic cruise, primarily through providing a mechanical diverging wall on the secondary flap.

The Low Base Drag Nozzle is made up in two components, a convergent and divergent nozzle, each separate from the other. Each of the two components is formed by using twenty-four flaps hinged at the forward ends. The flaps are further supported and positioned by an actuation ring. Twenty-four seals riding on the surfaces of these flaps complete each nozzle.

The secondary nozzle flaps have two positions. Fig. 9 shows at the top, the closed position which is used for non-reheat engine operation. Here, the boat-tail angle is 15° and, as can be seen, the primary stream is confined by the inner wall of the secondary flaps to reduce over-expansion losses. The open position is shown in the lower half of Fig. 9 and is used for all reheat operation, giving an external contour which is nearly cylindrical. The maximum primary nozzle area is adequate for reheat operation at stoichiometric fuel-air ratios and is fully modulating for intermediate flow areas. The nozzle weighs 330 lb., which is 9·2 per cent of the engine weight of the J79-5A.

Wind tunnel tests confirmed the best configurations and indicated a potential reduction in total drag of 5 per cent. Both the original ejector nozzle and the low-drag nozzle were compared in flight. The afterbody drags in flight were determined from an integration of the static pressures along the aft nacelle. The results of the flight tests agreed very well with the wind tunnel data, and showed that the expected drag saving of 5 per cent had, in fact, been realised.

Scale-model performance data with the secondary nozzle closed is shown in Fig. 10. The ordinate is the equivalent gross thrust coefficient. This coefficient charges the nozzle performance for the full ram drag of the secondary air flow, which is 4 per cent for the data shown. The abscissa is the flight Mach number. The important operating condition in each case is indicated by the heavy curve. As compared to the original ejector nozzle, the Low Base Drag Nozzle shows a worthwhile improvement in internal performance due primarily to providing a mechanical inner wall on the secondary

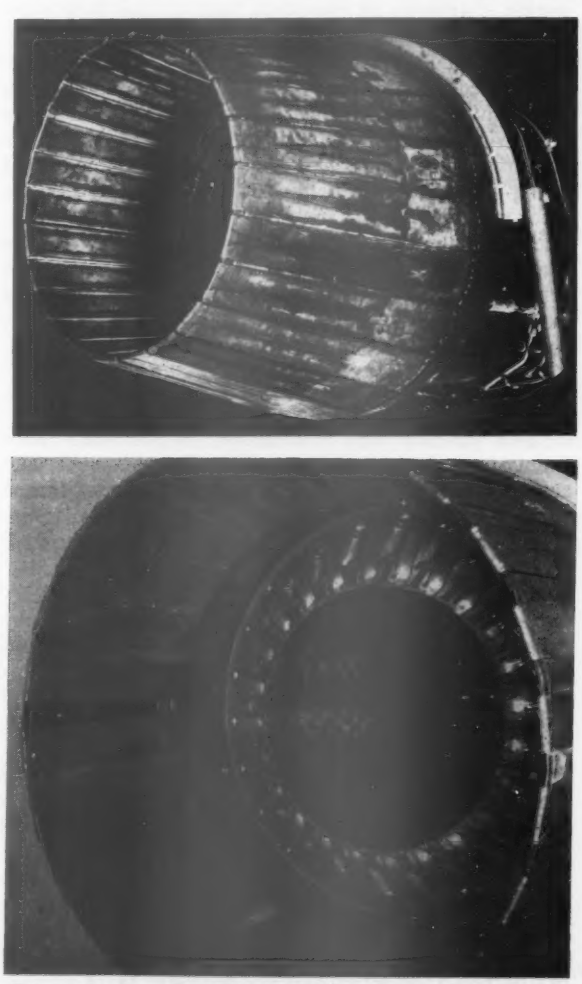


FIGURE 9. Low Base Drag Nozzle. *Above*, subsonic cruise position. *Below*, supersonic position with afterburning.

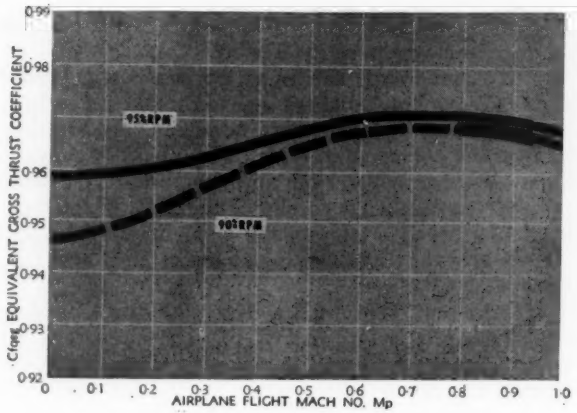


FIGURE 10. Nozzle Performance—subsonic cruise.

flaps. Full-scale tests at Arnold Engineering Development Center, and also at Convair Simulated Altitude Facility, gave thrust coefficients for non-augmented engine operation which agree well with the scale model testing. Analysis of the flight tests in the B-58 substantiated this level of thrust coefficient.

Additional scale model test data extending to supersonic speeds is shown on Fig. 11. The ordinate is again the equivalent gross thrust coefficient: the abscissa is flight Mach number. One of the two curves is for the military rating which is the maximum non-augmented rating with the secondary nozzle closed. The other line is for maximum reheat with the secondary nozzle open. The important operating conditions are indicated by the heavy portions of the curves. Again, compared with the original ejector nozzle, substantial improvements were made in installed performance at transonic and supersonic augmented operation.

Nozzle Leakage

The primary and secondary nozzles each have twenty-four flaps hinged at their forward ends and actuated by cam surfaces on the flaps and rollers attached to the translating actuation rings. The areas that require sealing are between adjacent flaps and between the flaps and their supporting structures.

Primary leakage becomes a part of the secondary stream entering the annulus between the exit of the primary flaps and the secondary flaps. The effectiveness of primary seals was determined by comparative tests on the same engine alternately equipped with fixed conical nozzles. These tests showed a leakage area varying between 1·0 and 2·2 square inches.

Air leaking through the secondary nozzle out to the atmosphere does not provide any useful thrust as it leaves the aircraft. Thus, secondary nozzle leakage loss acts in the same way as nacelle leakage, and in magnitude is approximately equal to the ram drag of the air that leaks. Attention to the seal design reduced the effective leakage area to about 15 square inches representing a net thrust loss of about 1·2 per cent at a flight Mach number of 0·9 (non-augmented) and also for flight Mach number of 2·0 at maximum reheat.

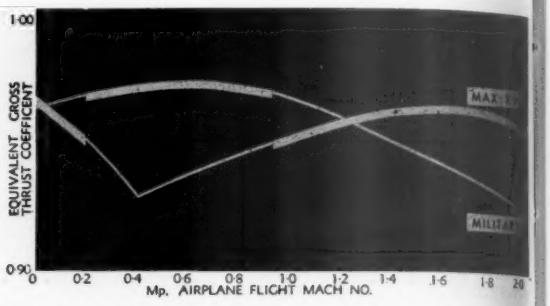


FIGURE 11. Performance of LBD Nozzle at different Flight Speeds.

Stability of Converging-Diverging Nozzle

During testing with the secondary nozzle in the open position a severe buffeting and vibratory condition arose in the divergent portion of the nozzle at pressure ratios between 2·5 to 3·8. Vibrational pickups installed on the nozzle fingers indicated a vibrational frequency of about 9 to 12 c.p.s., superimposed on an additional pattern of much lower and more random frequency. The maximum total amplitude of vibration was about 1·0 in. at the ends of the divergent fingers. Moving pictures and visual observations indicated that the nozzle was assuming an elliptical shape having four nodes and that this pattern tended to rotate slowly about the longitudinal axis of the engine.

Analysis of the vibratory motion was made by assuming that the actuation ring which supports and positions the secondary flap was also vibrating in the same pattern as the secondary flaps. This calculation supported the conclusion that the actuation ring and secondary flap system was vibrating at its own natural frequency of about 11 c.p.s. energised by aerodynamic instability.

The buffeting problem was completely eliminated by providing four equi-spaced axial slots in the diverging wall of the nozzle in order to stabilise the magnitude and position of the shock waves within the diverging section. The slots open into a space which is an extension of the plenum volume supplying the secondary air to the nozzle. When the secondary flaps are opened, the axial ventilating slots are tapered from 0·89 inches at the entrance to 2·01 inches at the exit. The total slot flow area is, in fact, 12·6 per cent of the primary throat area at the reheat operating condition where the severe buffeting occurred before slotting the diverging walls. When the secondary nozzle is in the closed position for subsonic cruise, the flaps are so close together that the stabilising slots are substantially closed off. Model tests indicate that the four axial slots account for a maximum loss of 1/10 of one per cent at design speed—which is within the accuracy of measurement.

Effect of Non-Uniform Secondary Air Flow

The secondary air system of the B-58 is supplied by three sub-inlets off the main induction system and exhausted through the jet nozzle. The possibility that non-uniform flow at the secondary inlet of the nozzle might adversely affect nozzle performance was investigated by scale model tests of the Low Base Drag Nozzle.

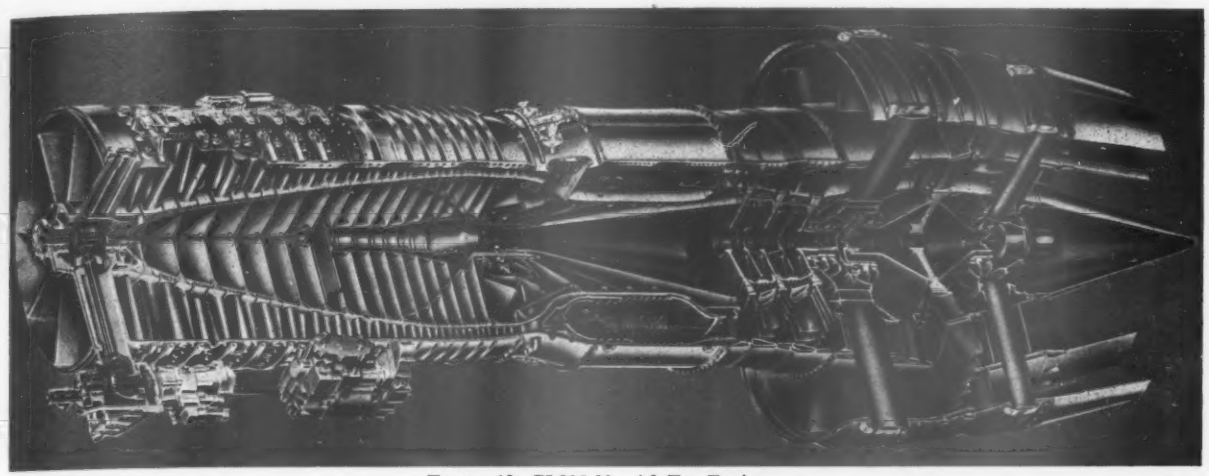


FIGURE 12. CJ 805-23. Aft Fan Engine.

Results showed that secondary inlet distortions up to 5 per cent in total pressure and 30 per cent in velocity caused no measurable change in either the thrust coefficient or pumping characteristics of the nozzle.

Approximately 9,500 flight hours have been accumulated on the Low Base Drag Nozzle without any problems. Of this total, over 250 hours of trouble-free operation have been accumulated on each of the engines on the Accelerated Service Test aeroplane.

The Aft Fan

Applications of ducted fan engines have so far been limited to subsonic aircraft. However, any study of power plants for supersonic transports should consider the ducted fan augmented by heating of the fan stream. The good qualities of low noise level, high take-off thrust, good specific fuel consumption for cruise and loiter are desirable for supersonic as well as subsonic transports. For example, a supersonic transport may use almost one-half of its fuel in such subsonic operations as take-off, climb, acceleration to supersonic cruise, descent, loiter, land, etc.

The aft fan engine has long been appreciated in England. Sir Frank Whittle described the basic configuration of aft fan engines many years ago and a pioneer application to a jet engine was made by Metropolitan Vickers in 1943.

General Electric have applied an aft fan to the civil version of the Military J79 engine just described. The fanned engine is known as the CJ 805-23 and is shown in cut-away form in Fig. 12.

Placing the fan aft leaves the gas generator operating characteristics unaffected. Since the main gas generator is separate from the fan unit, various configurations of fan designs can be added to suit different applications without compromising the development and service experience of the main gas generator. The engine is simply supported from trunnions located on the fan frames and on the gas generator compressor rear frame. The front support is bolted to the engine and accepts thrust and unbalanced engine torque in addition to the side and vertical acceleration loads.

A recent performance calibration of the CJ 805-23 aft fan engine is shown in Fig. 13. The lower curve is the initial calibration test made for the Federal Aviation Agency model test. The specific fuel consumption at each point is lower than guaranteed in the model specification shown by the upper curve. Following the stringent model test, the specific fuel consumption was still within 1·5 per cent of the initial calibration.

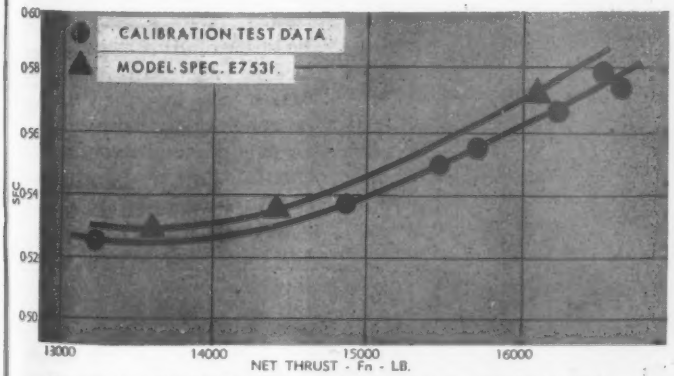


FIGURE 13. Test Performance on Aft-Fan Engine. Sea level static.

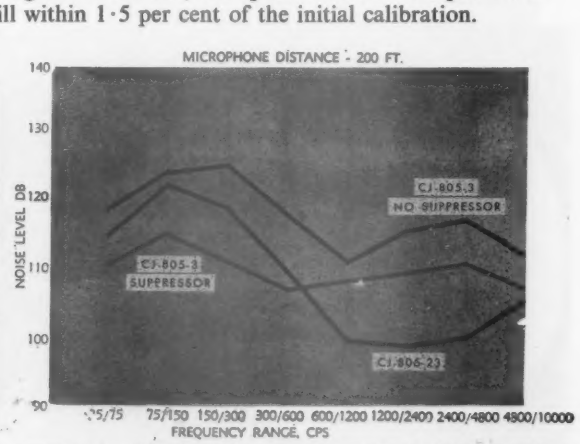


FIGURE 14. Noise Level Spectra, Turbo-jet and Aft Fan Engines.

The by-pass engine is inherently quieter than a straight turbo-jet engine of the same thrust. This is primarily due to the lower exhaust velocities. The higher the by-pass ratio of the fan, the lower the exhaust velocity and the resulting exhaust noise. High by-pass engines have an additional benefit in that a change in the frequency spectrum of the noise makes it more favourable on a perceived evaluation. The spectrum analysis shown in Fig. 14 compares the CJ 805-3 civil jet engine (with and without suppressor) with the CJ 805-23 aft fan. The diagram shows there is less high frequency noise from the aft fan engine and since the human ear finds the high frequency noise more objectionable, the perceived noise level of the aft fan is less.

With the lower exhaust noise of the fan engine, the compressor whine may be the predominant noise at the lower power settings, for example, on approach to landing. However, the noise level of the single-stage CJ 805-23 fan is as acceptable as that of the lower-powered turbo-jet.

Actual in-flight noise data has been recorded during fly-bys, for both take-off and approach conditions, using a converted B-66 powered by two CJ 805-23 fan engines. It has been found that the aft fan noise compares favourably with the suppressed turbo-jet data, even though the fan engine gives over 40 per cent more thrust at take-off.

The nacelle for the Convair CV-600 is shown fully opened-up in Fig. 15. It will be seen that a common induction system supplies air for both the gas generator and the aft fan.

The effect of inflow distortion on the fan was investigated in an aircraft pod with the access doors in the open position. With the access doors raised, it is possible to view the entire engine during ground running and the sharp stub ducts give a substantial fan inlet distortion because of the severe vena contracta effect. The distortion measured was 20 per cent and exceeds any flow distortion that the fan would experience during flight or ground operation with the pod access doors in the normal closed position. No fan stalls were encountered nor were the fan blade stress limits exceeded.

A unique component in the aft fan is a composite fan blade-turbine bucket, called the "blucket" shown in Fig. 16. A mid-span partition forming the interlocked blucket platforms, is used to maintain separation of exhaust gas and fan air. These interlocked platforms are effective in damping blade oscillatory stresses.

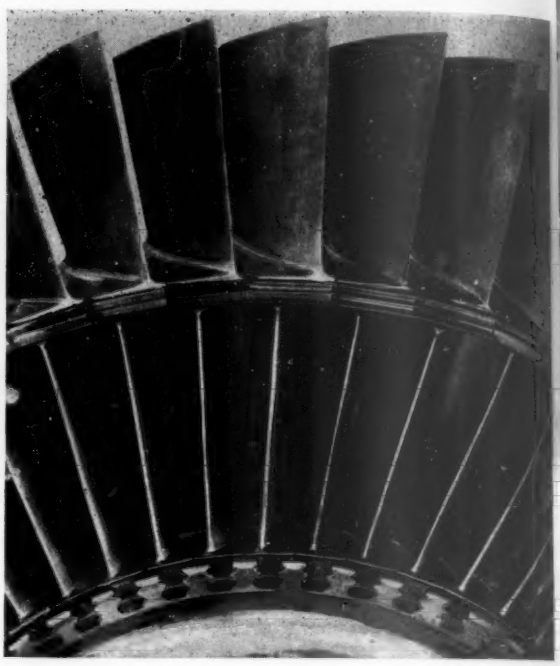


FIGURE 16. Combined Turbine and Fan Biade "Blucket".

Among the features contributing to good tolerance to inflow distortion is the high radius ratio of the fan compressor. Furthermore, because of the single stage fan, inflow distortion cannot cause mismatching of subsequent stages as in a multistage compressor. In any case, with the aft fan, ingestion of a distorted flow into the fan does not affect the basic gas generator.

Various types of inflow distortion were simulated on the aft fan engine to determine the effects on performance. The general set-up for the tests is shown in Fig. 17. The patterns of distortion tried simulated a thick boundary layer at the fan blade roots and a circumferential maldistribution as might be caused by the nacelle support pylon or the aft accessory box. Combinations of circumferential and radial flow distortions were also tested. With a maximum overall distortion of the order of 10 per cent, the maximum drop recorded in engine performance was 2·3 per cent—often it was less than this. These data support the conclusions that the fan is relatively insensitive to tip radial distortion, and also to circumferential distortion of one-per-revolution and two-per-revolution patterns. Performance losses occur when the fan is subjected to appreciable hub radial distortion.

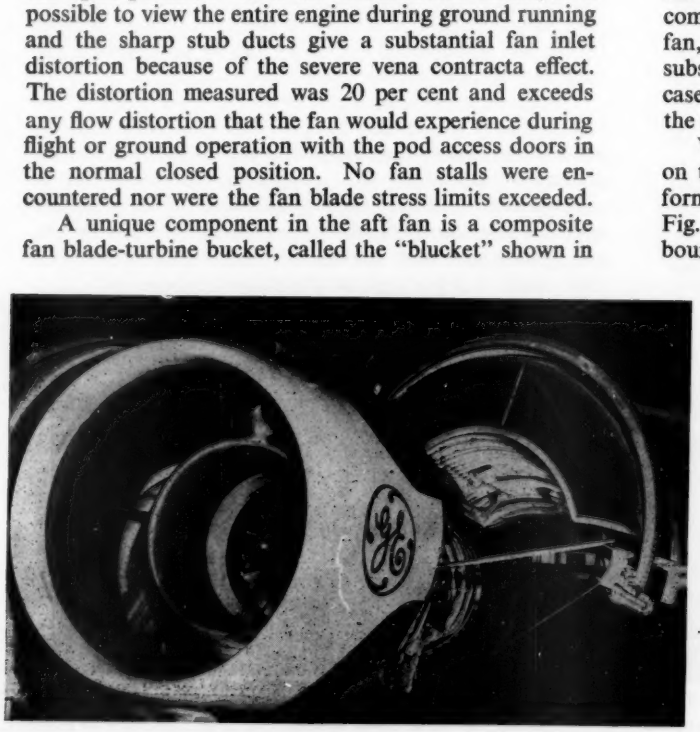


FIGURE 15. Fan Engine Nacelle for Convair 600.

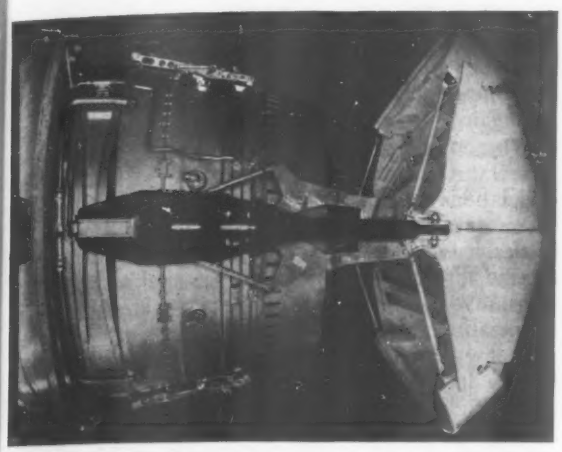


FIGURE 18. Thrust Reverser for CJ 805-23 Aft Fan Engine.

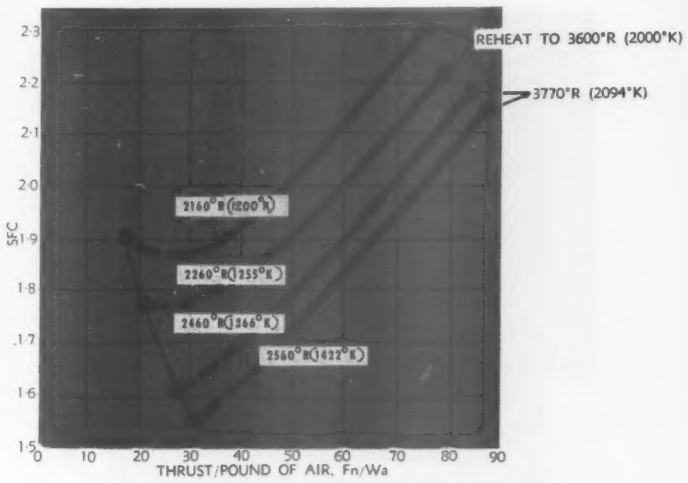


FIGURE 19. Effect of turbine entry temperature on thrust and fuel consumption at a Mach number of 3.

There is no mechanical coupling between the gas generator rotor and fan. However, tight aerodynamic coupling is demonstrated by acceleration tests. The total time of the transient for a throttle burst from ground idle speed to take-off r.p.m. is 5·6 seconds. The total time of the transient for a throttle burst from approach r.p.m. to full take-off r.p.m. is 2·6 seconds.

The thrust reverser of the CJ 805-23 fan is a two-position target type designed for ground use, and is actuated at engine idle power setting. A view in the reverse thrust position is shown on Fig. 18. When in the reverse position, the jet blockers redirect the gas generator and aft fan exhaust gas in a generally forward direction. When retracted the jet blockers blend into the engine pod forming a continuous aerodynamic surface. The system is actuated by piston-type hydraulic jacks through a multiplying linkage which imparts simultaneous translation and rotation to the blockers. Fail-safe requirements are such that the blockers remain in the committed position in event of failure of the actuation system. Adjustable lips are provided on the blockers for control of reingestion characteristics. These lips are linked to the main system in such a way as to form a smooth aerodynamic line with the blockers while stowed, and an acute angle with them in the reverse position.

Performance and reliability testing on this reverser has demonstrated a reverse thrust above 50 per cent of the main engine thrust with only small vibration effects (less than 0·050 in.). The characteristics of the adjustable lips are such that an increase of approximately one per cent reverse thrust occurs for each degree of angle increase between the lips and blocker. The total effect of the lip on reingestion and cross-ingestion characteristics has not yet been determined, but initial results are encouraging.

Mach 3 Propulsion—The J93 Turbo-jet

Thermodynamic cycle studies have revealed the effect of turbo-jet design parameters on missions at flight speeds of Mach 3. The effect of turbine inlet temperatures on specific fuel consumption and thrust is shown on Fig. 19 where the figures on the curves represent turbine inlet temperature. The dotted lines are for non-augmented operation: the solid lines for augmented

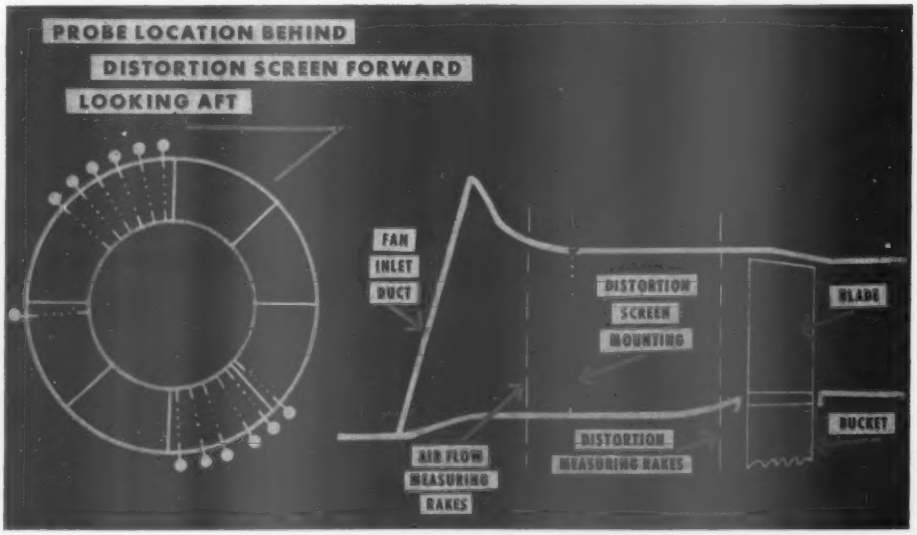


FIGURE 17. Air Flow Distortion Tests—Location of Instruments.

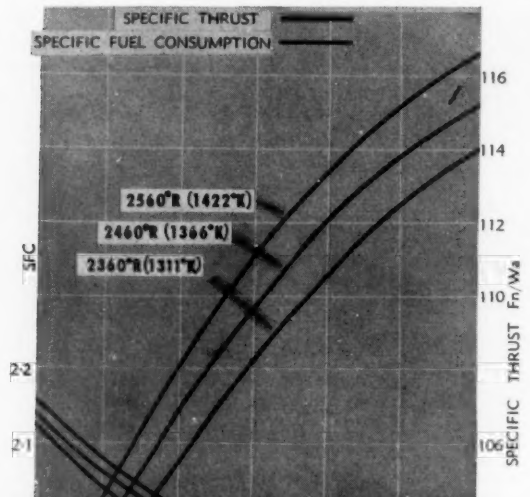


FIG. 20. Design Variables with Reheat—Sea level static condition.

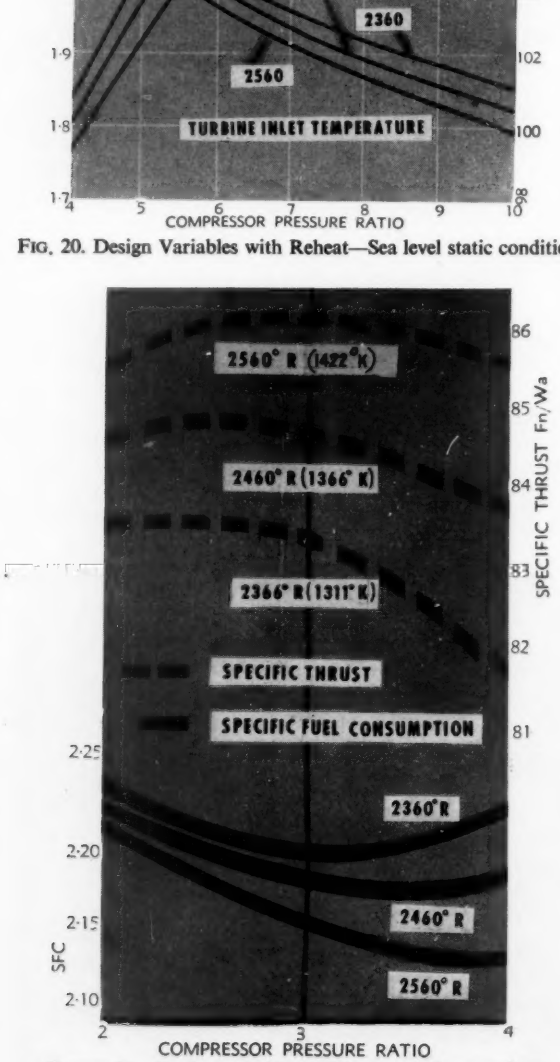


FIGURE 21. Design variables at $M=3$—maximum reheat.

operation. The amount of reheat varies from zero to a maximum exhaust temperature of 3,700°R. These data show the desirability of the highest possible turbine inlet temperature consistent with practicable and reliable mechanical design.

The optimum cycle pressure ratio and turbine inlet temperature are inter-related, as shown in Fig. 20. The calculations were made for sea level static operation and for maximum reheat power. The ordinate on the left is specific fuel consumption: the ordinate on the right is specific thrust. The abscissa is the design compressor pressure ratio while figures on the curves are turbine inlet temperature in degrees absolute.

For cruise at a Mach number of 3, the effect of turbine inlet temperature and cycle pressure ratio on specific fuel consumption and specific thrust are shown on Fig. 21. These calculations were made for maximum reheat power: the actual cruise would be at a reduced power setting for better SFC, the exact value being determined by aircraft requirements. The abscissa is the actual compressor pressure ratio at a flight Mach number of 3. The figures on the curves are the turbine inlet temperatures.

Figures 20 and 21 show that a high pressure ratio is desired at sea level static to obtain the maximum specific thrust, while a lower pressure ratio results in minimum specific fuel consumption for the high Mach cruise condition. Note that pressure ratio has a relatively small effect on specific thrust at the high Mach cruise condition: also that the SFC curves at the higher turbine inlet temperatures are relatively flat.

Take-off and supersonic cruise can be related through the turbine loading parameter, as shown in Fig. 22. A given value of turbine loading results in constant turbine exit conditions, such as exit velocity, swirl angle, and so on. The diagram shows the effect of compressor inlet temperature on compressor pressure ratio. The figures on the curves are turbine loading in B.Th.U./lb.

Now in its third year of development for the U.S. Air Force, the J93 turbo-jet was designed for flight at a Mach number of 3. Design principles used in the J93 were based largely on the J79, including such proven

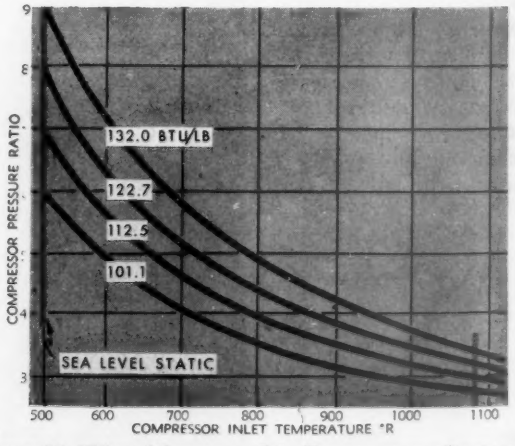


FIGURE 22. Effect of Compressor Inlet Temperature on Compressor Pressure Ratio for Various Turbine Loadings.

concepts as a variable-stator compressor, single shaft design, converging-diverging exhaust nozzle and light-weight construction. To meet the challenge of Mach 3 speeds, particularly with regard to high temperatures, the J93 utilises new high temperature alloys and honey-comb structures. The J93's operating cycle ensures high efficiency at Mach 3 cruise and provides long range at altitudes over 70,000 feet.

An interesting innovation is the arrangement of the controls and accessories in a removable "pod" to give protection from the high temperatures encountered at a Mach number of 3.

Future Prospects

With the J93 engine development well under way, the use of its gas generator in derivative versions is being studied. An aft fan configuration with afterburning in the fan stream has characteristics desirable for super-sonic transports. In the proposed arrangement the two streams, after mixing, are discharged through a single converging-diverging jet nozzle. For civil transport the gas generator would be operated at a lower turbine inlet temperature than the military version in order to achieve the longer life required. As we have seen, there is no particular requirement for high turbine inlet temperature at a Mach number of 3 unless the engine has a relatively high pressure ratio: even a ram-jet has about the same SFC if the combustion temperature matches a jet engine exhaust gas temperature. Throttling back reduces the turbine inlet temperature and the fan pressure ratio. Combustion in the fan stream produces the same exhaust gas temperature as the high-pressure-ratio, high-turbine-inlet temperature jet engine would have.

Comparison of specific fuel consumptions for different types of engine operating at maximum thrust is shown on Fig. 23. Assumptions made in calculating these curves are that the turbine-inlet temperature is 2,460°R for both non-augmented and reheat turbo-jet, and 2,260°R for the reheat fan. The maximum temperature in the fan stream was varied from 0 to 2,000°R to give the best cruising specific fuel consumption.

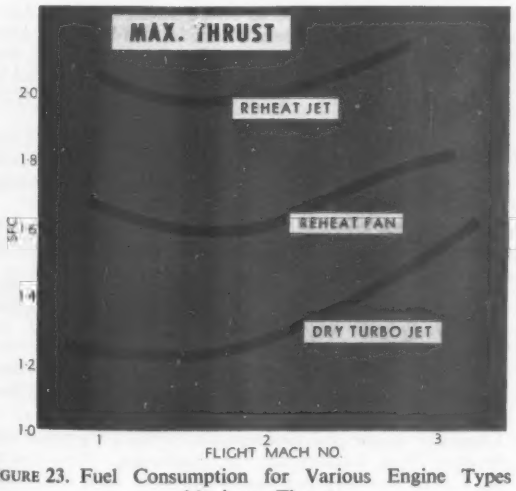


FIGURE 23. Fuel Consumption for Various Engine Types at Maximum Thrust.

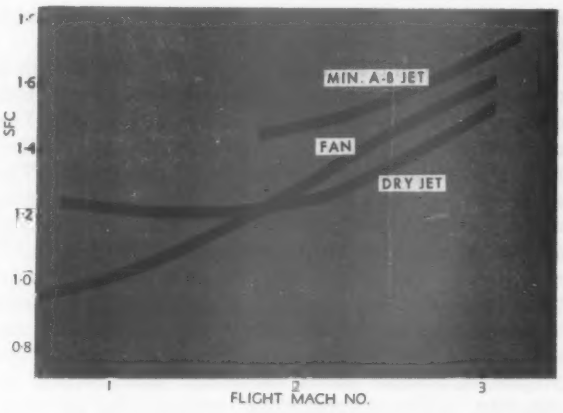


FIGURE 24. Fuel Consumption for Various Engine Types at Cruise Thrust.

The aft fan with heating of the fan stream has a relatively low noise level. For a given take-off thrust, minimum exhaust noise would be obtained by having the exit velocity of the main gas generator and the by-pass substantially the same. That is, the by-pass flow ratio is determined to meet the exhaust noise requirements for sea level operation. There seems to be no compelling reason for providing reheat in the main primary stream, except possibly to provide a torch igniter to initiate and facilitate combustion in the fan stream. Simplification of mechanical problems is obtained by limiting the burning to the aft fan stream.

High thrust for take-off and acceleration is of vital importance to transport aircraft designed to cruise at supersonic speeds between Mach numbers of 2 and 3. The aft fan with combustion in the fan stream has high thrust for take-off and acceleration due to high air flow capacity and heating of the fan stream. A comparison of the thrusts available for acceleration with different power plants is shown on Fig. 25. The ordinate is the ratio of the acceleration thrust to take-off thrust (both

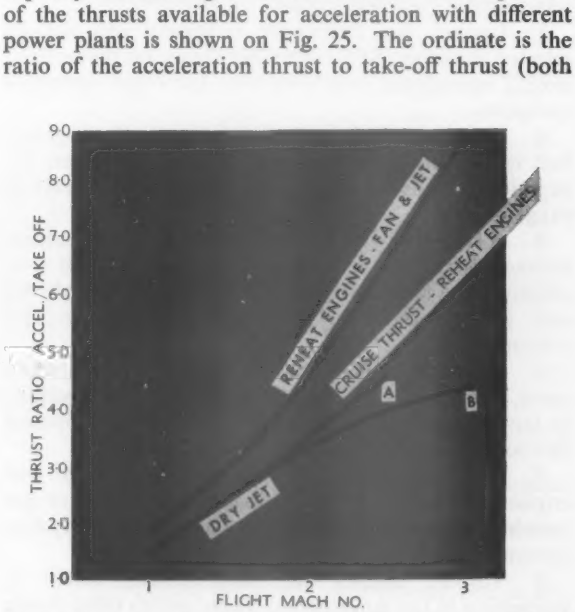


FIGURE 25. Accelerating Thrusts with Different Power Plants.

measured at the same ambient pressure): the abscissa is the flight Mach number.

The fan engine improves the air flow match with a constant-capture-area inlet. The basic problem of inlet duct/engine air flow match is shown in Fig. 26. The ordinate is the air flow in pounds per second, divided by ambient pressure in pounds per square foot. The abscissa is flight Mach number. The studies include inlets whose capture area is sized to provide adequate engine air flow at design flight Mach numbers of 2, 2·5, and 3 respectively. The lowest line is the air flow capacity of a typical turbo-jet engine. The vertical distance between this lowest curve and the curves above represents the spillage air flow, which causes additional drag. The propulsion system should have the characteristic of ingesting, without appreciable spillage, the air flow capacity of a constant-capture-area inlet sized to provide adequate engine air flow at the design flight Mach number.

The excess thrust capacity of an aft fan engine provides a flexibility for improved air flow match with the induction system. At supersonic cruise the aft fan engine is throttled back to achieve lower pressure ratio and lower turbine inlet temperature than a turbo-jet would have. This throttling back also reduces the air flow capacity at the design condition. Large air flow capacity, as is required at transonic and low supersonic speeds, is obtained by operating at maximum r.p.m.

Conclusions

1. Development of military turbo-jet engines for speeds of a Mach number of 2–3 has provided the state-of-the-art knowledge, production know-how, and operational experience necessary to produce a supersonic transport engine.

2. The cruise speed must first be decided upon before selecting the optimum engine.

3. Engines for supersonic transport will not be selected for cruise SFC alone, but rather on the basis of overall operational capability over the entire operating spectrum.

4. The non-augmented turbo-jet has excellent specific fuel consumption at supersonic cruise. However, the superiority is not maintained over the wide operating range of speed.

5. A fan with by-pass burning combines the desirable characteristics of the ram-jet and the turbo-jet. In addition, the fan has low noise, high thrust for take-off and acceleration, and good subsonic specific fuel consumption.

6. The aft fan engines are outstanding as regards low noise, tolerance to inflow distortion, and broad flexibility in fan design which does not compromise development and service experience of the main gas generator.

7. Close co-ordination between the airframe and engine manufacturers will be necessary to ensure proper matching of the induction system, engine, secondary flow system, and nozzle design.

8. Turbine engines are fundamentally suited to propulsion in the atmosphere. There are no other power plants in existence today, or in the offing for the future, which threaten the supremacy of the turbine engine for atmospheric flight.

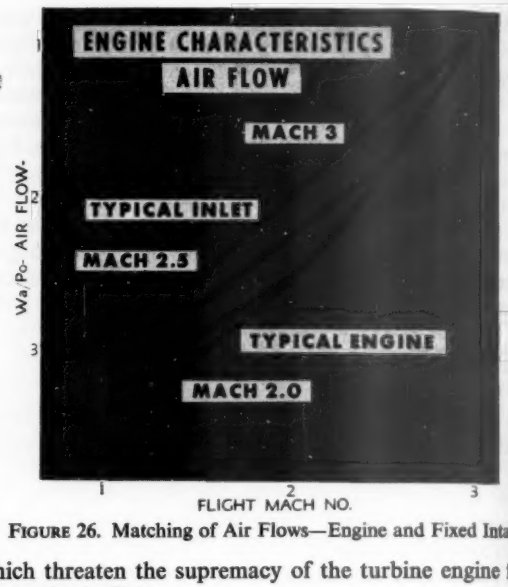


FIGURE 26. Matching of Air Flows—Engine and Fixed Intake.

ACKNOWLEDGMENT

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TECHNICAL NOTES

A Controlled Experiment on the Perception of Helicopter Rotor Noise

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(National Gas Turbine Establishment)

DURING A RECENT OPEN WEEK at the National Gas Turbine Establishment at Pyestock, an experiment involving just over 1,000 subjects was made to establish some measure of the disturbance value of such rhythmic or amplitude modulated noises as are generated by helicopter rotors. The results were (*i*) that, as may be implied from Niese's[1] results with modulated tones, the subjective assessment of such a noise depends upon its peak sound pressure level (*i.e.* 82·5 db. in Fig. 3) rather than upon its r.m.s. value, (*ii*) that the effect of the modulation frequency is negligible in the range from 4 to 12 cycles/sec. and (*iii*) that these results are invariant with peak sound pressure level in the range from 85 to 95 db. re 2×10^{-4} dynes/cm^2.

For the assessment of helicopter operations from city centres there has so far been no established method of assigning to their noise an effective P.N.db. rating. On the one hand the modulation frequency of the rotor noise will normally be such that its sound pressure level (S.P.L.) cannot easily be measured. On the other hand, even when adequate laboratory type equipment is available for this physical measurement, there is no established way in which it can be converted to a measure of disturbance.

Subjectively, two factors might conceivably have been involved; the way in which the hearing system perceives an amplitude modulated noise in general, and any gross effect which might arise from the synchronism of the modulation frequency with the basic rhythms in the brain. The first of these factors has already been studied by Niese[1], working with modulated pure tones; but there is no information relating to a modulated complex noise, and α-rhythm synchronism may well have been missed in Niese's experiments since they were conducted with only 20 experimental subjects.

This larger scale experiment, involving 1,009 subjects ranging in age from 10 to 70 years, was conducted in the same theatre with the same acoustic equipment as was used in the jet engine noise experiment at the 1959 Farnborough Air Show[2]. As on that occasion, the audience was first shown a 15 minute demonstration film on jet engine noise and then, following a short plea for co-operation from the steward in the theatre, the tests began with an announcement from the loudspeakers which concluded:—

"We shall announce each pair of noises as it comes and you will have two or three seconds between one pair and the next to record your decision. Even if you are doubtful, a guess will be more valuable to us than a blank space on your paper.

"Once again then, please record with a tick in the appropriate box on your paper which of the two noises in each pair you consider to be the more disturbing.

"Test number one ....."

In all there were four test (magnetic) tapes, coded for convenience "Red", "Yellow", "Green" and "White". The thirty-two noises (sixteen pairs) on each tape were individually "faded up" over about 0·2 seconds, held for four seconds and then "faded down" over 0·2 seconds.

The composition of the Red and Green tapes is that of Table I, while in the Yellow and White tapes the test sequence was the same but the internal order in each pair was reversed, *i.e.* $(B+2)^*$ versus $(A-2)$ instead of $(A-2)$ versus $(B+2)$. With Red and Yellow the datum level of all four noises, *A*, *B*, *C* and *D*, on the tape was such that their peak level in the theatre was 85 db. re 2×10^{-4} dynes/cm.^{2} at the monitoring microphone position. With the Green and White tapes it was 95 db.

Because of their engine noise, the sounds of existing helicopters vary considerably in quality and are not always typical of those which may be operated in the future. Furthermore, the object of this experiment involved only one main variable, namely, the modulation frequency of the rotor noise. In the interests of precision, therefore, the experiment was based on simulated rotor noise alone, the method of synthesis being as follows.

Noise *A* of this experiment was in fact the sound of a typical jet aircraft at take-off (*see* Fig. 1).

The noises *B*, *C* and *D* were then obtained by modulating noise *A* in the manner shown in Fig. 2, the depth of modulation being 8 db. between the peak and trough levels on the tape and the modulation frequencies being respectively 4, 8 and 12 cycles/sec.

TABLE I
COMPOSITION OF THE "RED" AND "GREEN" TAPES

	First noise db.	*Second noise* db.		*First noise* db.	*Second noise* db.
Test 1	(*A*—2)	(*B*+2)	Test 2	(*C*+1)	(*D*—1)
Test 3	(*B*—2)	(*C*+2)	Test 4	(*A*—1)	(*C*+1)
Test 5	(*D*—2)	(*C*+2)	Test 6	(*C*+1)	(*B*—1)
Test 7	(*A*+1)	(*C*—1)	Test 8	(*B*—2)	(*A*+2)
Test 9	(*B*+1)	(*C*—1)	Test 10	(*C*—2)	(*A*+2)
Test 11	(*B*+1)	(*A*—1)	Test 12	(*C*—1)	(*D*+1)
Test 13	(*C*+2)	(*A*—2)	Test 14	(*A*+1)	(*B*—1)
Test 15	(*D*+2)	(*C*—2)	Test 16	(*C*—2)	(*B*+2)

Note: These are electrical levels, the noises being:—
A—A typical jet aircraft at take-off
B—Synthesised helicopter rotor noise (*A* modulated at 4 cycles/sec.)
C—Synthesised helicopter rotor noise (*A* modulated at 8 cycles/sec.)
D—Synthesised helicopter rotor noise (*A* modulated at 12 cycles/sec.)

*The notation signifies the overall sound pressure level in db.; *A*, *B* and so on being the datum levels of the noises *A*, *B* and so on.

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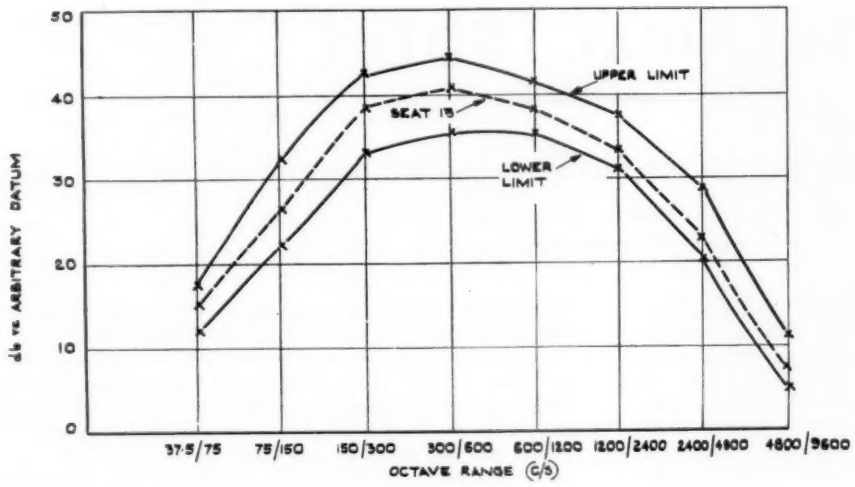


FIGURE 1. Octave band spectrum of basic noise *A* as reproduced in theatre.

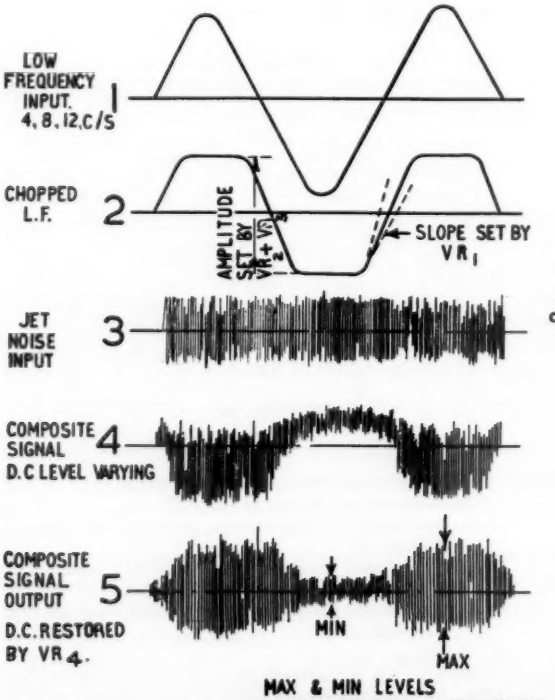
To avoid trouble with such loudspeaker transients as are excited by a step input the modulation envelope was not in fact a square wave, but had sloping sides as illustrated, the precise shape being unimportant since it was much modified by the theatre acoustics. By trial and error a modulation envelope was thus found which gave throughout the theatre the most realistic simulation of a real helicopter rotor noise.

Since the basic noise *A* was that of a jet, the quality of *B*, *C* and *D* was quite representative of vortex noise and therefore equally applicable to mechanically or tip jet driven rotors. In calibrating the theatre the variation of S.P.L. with time was checked at every seat position by placing a microphone at head level above each seat in turn in an otherwise full theatre, a typical result—for seat No. 13—being illustrated in Fig. 3.

As in the 1959 jet noise experiment the programme cycle was half an hour, so that the monitoring procedures were just as before[2], except that the reverberation time in the theatre also was checked for each test.

Since the analysis of the results was to be based on instantaneous peak sound pressure level, rather than on such a mean level as would be recorded by any standard noise measuring equipment in the presence of low frequency amplitude modulation, the instantaneous S.P.L. values were obtained in the manner illustrated in Fig. 4. That is, by the use of such a detector circuit as will give an r.m.s. output in response to audio frequencies, but will pass the low frequency modulation envelope virtually unattenuated, as in Fig. 3.

In analysing the audience replies, any bias in judgement caused by the order of presentation within each noise pair was first automatically minimised by combining the results for the complementary tapes, *e.g.* Red and Yellow. Furthermore, since a preliminary analysis showed that there was no significant difference between the Red-Yellow results (85 db.) and the Green-White (95 db.), the final result as reported here was obtained by summing the audience replies from all four tapes.



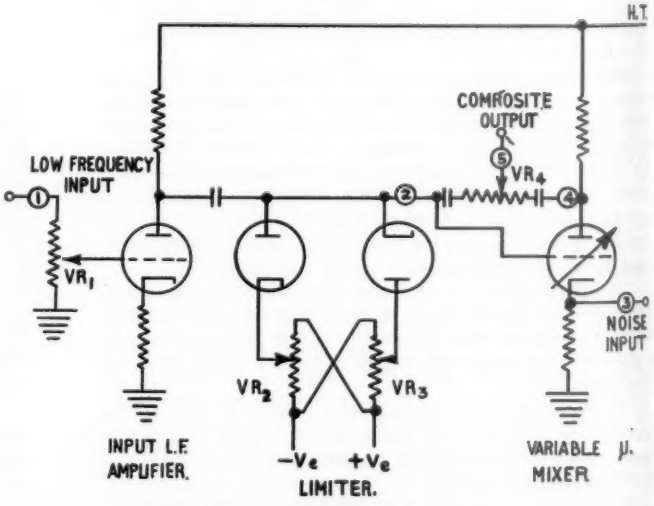


FIGURE 2. Rotor noise synthesis.

TABLE II

SOUND VARIATION OF INDIVIDUAL NOISES FROM THEIR DATUM LEVEL IN THE THEATRE

Seat number	*Deviation of peak S.P.L. from mean for theatre*			
	A db.	*B* db.	*C* db.	*D* db.
1	+0·75	—0·67	+0·92	+1·12
2	—0·09	—0·03	+0·02	+0·34
3	+0·41	+0·39	+0·06	+0·3
4	+1·35	+1·59	+1·14	+1·5
5	+0·69	—0·03	+0·12	0
6	—0·11	—0·53	—1·18	—0·2
7	+0·59	+1·37	+1·62	+1·3
8	—1·21	—0·53	—0·98	—2·1
9	—0·49	—0·65	—0·20	—0·20
10	—1·89	—2·73	—1·22	—2·10
11	—2·09	—2·17	—1·68	—2·18
12	+0·09	—0·25	—1·00	+0·30
13	—2·31	—2·49	—2·41	—1·36
14	—1·87	—0·85	—0·68	—1·90
15	+1·97	+1·57	+0·72	+1·30
16	—1·20	—1·29	—1·28	—0·76
17	—0·71	—0·19	+0·36	—0·44
18	+1·39	+1·37	+0·74	—1·30
19	—1·31	—1·39	—1·46	—0·6
20	+2·65	+2·87	+2·96	+1·30
21	+3·39	+3·47	+3·04	+2·98

Once again, there were two main difficulties in the analysis:—

(*i*) that, as a result of the theatre resonances, there were for certain modulation frequencies one or two acoustically "bad" seats and

(*ii*) that since, even summing all four tapes, the maximum number of performances was only 56, the treatment of each seat as an individual experiment could not yield the 100 or more subjects required, statistically, to give a result within ±1 db.

These two difficulties were resolved by grouping the seats together in sets, the differences of the weighted mean peak sound pressure levels of the compared noises being within ±0·1 db. in each set; *i.e.* in one set this difference would be the design value ±0·1 db., in another +0·1 to +0·3 db., in a third −0·3 to −0·1 db. and so on. Any set in which the total number of subjects was substantially less than 100 was then discarded.

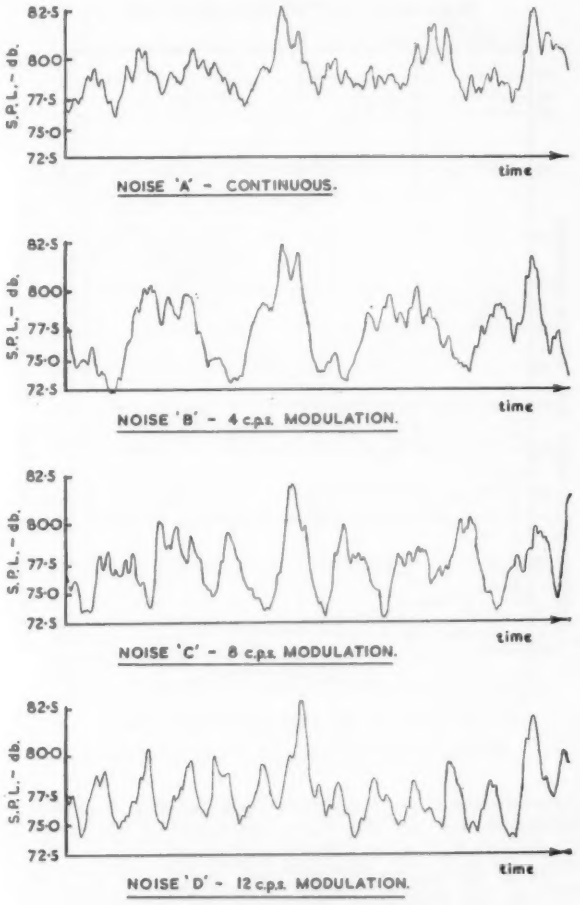


FIGURE 3. S.P.L. at seat No. 13.

Using such a method the final results were obtained by Probit analysis, a typical example being that of Fig. 5 from which it may be seen that the disturbance equality is obtained when the peak S.P.L. of noise *A* is 0·34 db. higher than that of noise *B*. The accuracy of the whole investigation is then given by Table III from which it will be seen that, while the statistical error in any one comparison might be 0·5 db., the check "triangle" *ABCA* was closed to within a half of this value. The worst statistical

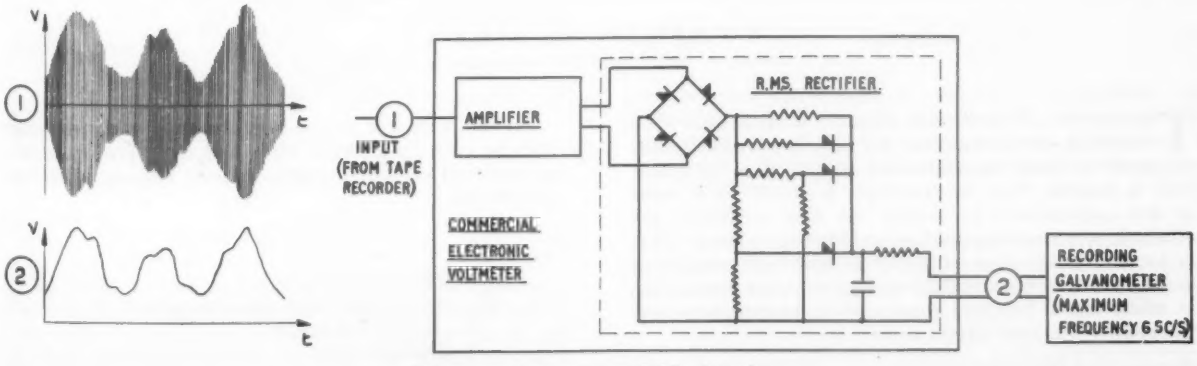


FIGURE 4. Instantaneous S.P.L. detection.

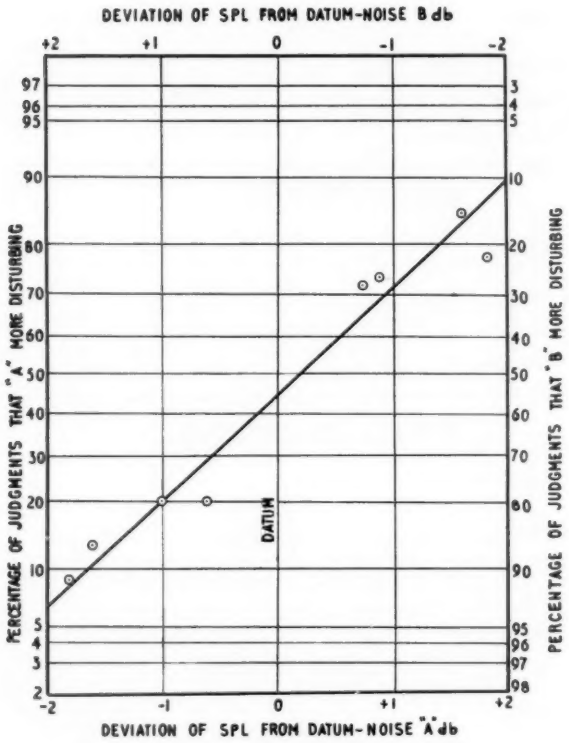


FIGURE 5. Probit treatment of *A*-*B* comparison.

error—in the *C*-*D* comparison—was due not to audience indecision but to the basic difference in the theatre acoustical behaviour at 8 and 12 cycles/sec.

With the reservation that they apply only to within ±1 db., the provisional findings of this investigation are, therefore, as follows:—

(*i*) That the disturbance value of the noise of a helicopter rotor, be it mechanically or jet driven, should be taken as the P.N.db. value of its instantaneous peak level.

(*ii*) That with conventional hand held noise meters, however used, the measurement of this instantaneous peak level and therefore of helicopter rotor noise is impracticable, the error varying with the structure of the noise and being perhaps 5 db. or more.

(*iii*) That conclusion (*i*) is unaffected by modulation frequency within the range of 4 to 12 cycles/sec., there being no evidence of gross α-rhythm effects.

(*iv*) That in the practical range of 85 to 95 db. re 2×10^{-4} dynes/cm.^{2}, or perhaps a little more, these conclusions are also invariant with noise level.

(*v*) Experience in the theatre preparation and calibration suggests that, when a correction is to be applied for "indoor listening" in practice, careful account should be taken of the sound magnification produced by room resonance.

TABLE III
THE PROVISIONAL NUMERICAL RESULTS

Noise comparison		$(y\text{-}x)$* *at equal disturbance*
Noise x	*Noise y*	*Peak S.P.L.* db.
Jet Aircraft (*A*)	Simulated 4 c./sec. rotor (*B*)	—0·34±0·12
Simulated 4 c./sec. rotor (*B*)	Simulated 8 c./sec. rotor (*C*)	+0·46±0·5
Jet aircraft (*A*)	Simulated 8 c./sec. rotor (*C*)	+0·3±0·44
Same by comparison of first two lines		+0·12±0·62
Simulated 8 c./sec rotor (*C*)	Simulated 12 c./sec. rotor (*D*)	—0·04±0·84

*In the S.P.L. column a negative value signifies that *y* is "more disturbing" for the same S.P.L.

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Diabatic Nozzle Flow with Constant Small Stage Efficiency

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THE CONCEPT of small stage efficiency is introduced when studying one-dimensional gas flow in nozzles in order to permit a closer approximation of real flow conditions than is possible from an isentropic analysis. It is more or less conventional to assume the flow conditions are adiabatic whenever the small stage efficiency is used. That is to say, small stage efficiency is generally considered in relation to flows contained within adiabatic boundaries, in which case it becomes a measure of the heat generated by internal frictional effects alone.

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In this note it is shown how the small stage efficiency may be used for diabatic flows and some properties of a hypothetical class of diabatic constant efficiency flows are determined.

NOTATION

A area of nozzle
C_p specific heat at constant pressure
D diameter of nozzle
f friction factor
$h=C_pT$ specific enthalpy

k wall heat transfer coefficient
M local Mach number
m mass flow rate
N reduced velocity
n polytropic state path index
p static pressure
p_0 isentropic stagnation pressure
Q heat added (or extracted) per unit mass
R gas constant
S specific entropy
T static temperature
T_0 isentropic stagnation temperature
T_w wall temperature
T_{aw} adiabatic wall temperature
V local velocity
x distance along nozzle axis (positive in direction of flow)
γ ratio of specific heats
η small stage efficiency
ϕ wall tangent angle relative to x positive direction
ρ density

Suffixes

t condition at throat of nozzle
1 datum point in nozzle

* indicates values under critical ($M=1$) conditions. Primed (′) variables indicate values for isentropic process.

SMALL STAGE EFFICIENCY

Consider steady one-dimensional diabatic flow of perfect gas through a nozzle of circular cross-section, the walls of which have a steady temperature distribution $T_w=T_w(x)$ due to both heat transfer from the surroundings and heat conduction along the nozzle itself.

As is usual in diabatic flows the isentropic stagnation temperature T_0 and enthalpy h_0 will not be of constant magnitude, nor will be the isentropic stagnation pressure p_0.

We assume a polytropic relationship between the state parameters and define small stage efficiency by comparing the rate of change of enthalpy dh/dx at some point along the nozzle with the corresponding change which would occur for an isentropic expansion under the same pressure gradient dp/dx as in the real process, Fig. 1.

Thus we write

$$\eta=\frac{dh}{dx}\Big/\frac{dh'}{dx} \quad . \quad . \quad . \quad . \quad (1)$$

Now by the First and Second Laws of Thermodynamics,

$$\frac{dh}{dx}=T\frac{dS}{dx}+\frac{1}{\rho}\frac{dp}{dx} \quad . \quad . \quad . \quad (2)$$

$$\frac{dh'}{dx}=\frac{1}{\rho}\frac{dp}{dx}\ ; \quad . \quad . \quad . \quad (3)$$

it follows that

$$\eta=1+\rho T\left(\frac{dS}{dx}\right)\left(\frac{dx}{dp}\right) \quad . \quad . \quad . \quad (4)$$

or, by the Equation of State,

$$\frac{p}{\rho}=RT, \quad . \quad . \quad . \quad . \quad (5)$$

$$\eta=1+\frac{p}{R}\left(\frac{dS}{dx}\right)\left(\frac{dx}{dp}\right). \quad . \quad . \quad (6)$$

In terms of (4) or (6), η will be a single-valued continuous function if the flow is shock free. But it will be of limited use, since to evaluate it we must know $p=p(x)$ and $S=S(x)$; and these are the variables with which we would like to deal in terms of η.

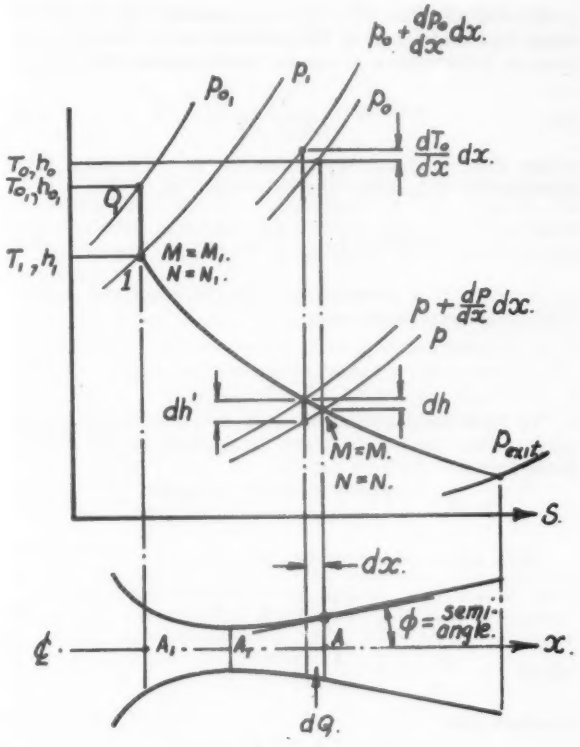

FIGURE 1.

We elude the difficulty if we consider η to be constant and the flow shock free; in fact, little more can be said unless these assumptions are made. By them we restrict attention to a particular type of diabatic flow in which

$$\frac{dS}{dx}=(\eta-1)R\frac{d\log_e p}{dx} \quad . \quad . \quad . \quad (7)$$

and other properties of which can be determined. The flow follows a simple polytropic (n=constant) law. That is to say, if we use (2) to write

$$\frac{dS}{dx}=C_p\frac{d\log_e T}{dx}-R\frac{d\log_e p}{dx} \quad . \quad . \quad (8)$$

and substitute, from consideration of a polytropic process,

$$\frac{d\log_e T}{dx}=\frac{n-1}{n}\cdot\frac{d\log_e p}{dx} \quad . \quad . \quad (9)$$

to find

$$\eta=\left(\frac{n-1}{n}\right)\left(\frac{\gamma}{\gamma-1}\right) \quad . \quad . \quad (10)$$

we can conclude n must be constant if η is constant. On the other hand if $\eta=\eta(x)$, then $n=n(x)$ will be a variable polytropic exponent. Although a variable n is realistic it cannot be handled for the reason stated in assuming constant efficiency.

DIABATIC FLOW WITH CONSTANT SMALL STAGE EFFICIENCY

Properties of diabatic flow with constant small stage efficiency may be discovered by using the equation of conservation of mass[1],

$$m=A\left(\frac{\gamma}{RT_0}\right)^{\frac{1}{2}}pM\left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{1}{2}}. \quad (11)$$

In diabatic flow (11) may be applied only to points along the flow because of the variation in T_0. For our purposes it is convenient to use the local reduced velocity,

$$N=\frac{V}{(2C_pT_0)^{1/2}}, \quad . \quad . \quad (12)$$

rather than the local Mach number, M. Equation (11), rewritten in N notation and rearranged is,

$$m(RT_0)^{\frac{1}{2}}\left(\frac{\gamma-1}{2\gamma}\right)^{\frac{1}{2}}=\frac{pAN}{1-N^2}. \quad . \quad (13)$$

Similarly it is possible to write the isentropic stagnation/static temperature ratio,

$$\frac{T_0}{T}=\frac{1}{1-N^2}. \quad . \quad . \quad . \quad (14)$$

To refer local conditions back to an arbitrary datum point within the nozzle (suffix 1) equation (13) is written in the form,

$$m(RT_{01})^{\frac{1}{2}}\left(\frac{\gamma-1}{2\gamma}\right)^{\frac{1}{2}}=\left(\frac{T_{01}}{T_0}\right)^{\frac{1}{2}}\frac{pAN}{1-N^2}. \quad . \quad (15)$$

Here, with n=constant, we can state

$$\frac{p}{p_1}=\frac{p}{p_{01}}\left(\frac{p_{01}}{p_1}\right)=\left(\frac{T}{T_1}\right)^{n/(n-1)} \quad . \quad (16)$$

where $$\frac{p_{01}}{p_1}=\left(\frac{1}{1-N_1^2}\right)^{\gamma/(\gamma-1)}; \quad . \quad . \quad (17)$$

it follows that

$$\frac{p}{p_{01}}=\left(\frac{p_1}{p_{01}}\right)\left(\frac{T}{T_1}\right)^{n/(n-1)}$$

$$=(1-N_1^2)^{\gamma/(\gamma-1)}\left(\frac{T}{T_1}\right)^{n/(n-1)} \quad . \quad (18)$$

Also it is possible to state, using (14),

$$\frac{T}{T_1}=\frac{T}{T_0}\left(\frac{T_0}{T_{01}}\right)\frac{T_{01}}{T_1}$$

$$=(1-N^2)\left(\frac{T_0}{T_{01}}\right)\left(\frac{1}{1-N_1^2}\right), \quad (19)$$

whence

$$\left(\frac{T}{T_1}\right)^{n/(n-1)}=\left(\frac{1-N^2}{1-N_1^2}\right)^{n/(n-1)}\left(\frac{T_0}{T_{01}}\right)^{n/(n-1)} \quad . \quad (20)$$

in equation (18).

Thus, using (18) and (20) to eliminate p in (15) and remembering (14) and (17) we find,

$$m\left(R\frac{\gamma-1}{2\gamma}\right)^{1/2}\frac{T_1}{p_1}^{n/(n-1)}=T_0^{(n+1)/2(n-1)}AN(1-N^2)^{1/(n-1)}$$

. . (21)

where the left-hand side defines the flow and the terms on the right-hand side give the particular relationship between A, N and T_0 for diabatic flows satisfying (7).

It follows immediately from (21) that,

$$\frac{A}{A_1}=\left(\frac{N_1}{N}\right)\left(\frac{1-N_1^2}{1-N^2}\right)^{1/(n-1)}\left(\frac{T_{01}}{T_0}\right)^{(n+1)/2(n-1)} \quad . \quad (22)$$

One interesting result is obtained for flow with constant reduced velocity (which implies constant local Mach number). If N=constant, it is necessary for

$$T_0^{(n+1)/2(n-1)}A=\text{constant} \quad . \quad . \quad (23)$$

and $$T^{(n+1)/2(n-1)}A=\text{constant}. \quad . \quad . \quad (24)$$

Corresponding results for adiabatic flow are

$$p_0A=\text{constant}$$

and $$pA=\text{constant} \quad . \quad . \quad (26)$$

which represent the familiar $p-A$ family of ducts, known to diverge both for subsonic and supersonic (constant) velocities.

In the present case we note, from (23), the area variation depends on T_0 and hence on the heat transferred through the walls. By differentiating (23) and (24) to get,

$$\frac{dA}{dx}=-\frac{(n+1)}{2(n-1)}\frac{A}{T_0}\frac{dT_0}{dx}; \quad . \quad (27)$$

$$\frac{dA}{dx}=-\frac{(n+1)}{2(n-1)}\frac{A}{T}\frac{dT}{dx}, \quad . \quad (28)$$

it is seen that A should decrease if heat is being added ($dT_0/dx>0$) and increase if heat is being removed ($dT_0/dx<0$); also the sign of dT/dx will be the same as dT_0/dx.

Adiabatic flow ($dT_0/dx=0$) with constant reduced velocity cannot be considered using the small stage efficiency approach; the usual meaningless result is obtained from (23) and (27) but note, as dT/dx is always negative in adiabatic nozzle flows, how (24) and (28) tell us A must increase. And, of course, (26) is a special case of (15).

More generally, diabatic constant η flows with varying reduced velocity may be studied by differentiating (22) to obtain

$$\frac{dA}{dx}+\frac{n+1}{2(n-1)}\frac{A}{T_0}\frac{dT_0}{dx}+\frac{A}{N}\left[1+\frac{2N^2}{(N^2-1)(n-1)}\right]\frac{dN}{dx}=0.$$

. . (29)

We restate dT_0/dx by considering the heat flow through the wall and the geometry of the nozzle. Firstly, the rate of heat flow through the walls bounded by length dx will be,

$$\rho AV\,dQ=k(T_w-T_{aw})\cdot\frac{\pi D\,dx}{\cos\phi}. \quad . \quad (30)$$

From the geometry of the nozzle it is easy to show

$$\frac{\pi D}{A}dx=\frac{1}{\tan\phi}\frac{dA}{A} \quad . \quad . \quad . \quad (31)$$

and hence, putting $dQ=C_pdT_0$ we see from (30)

$$\frac{dT_0}{dx}=k\frac{(T_w-T_{aw})}{\rho VC_pA\sin\phi}\frac{dA}{dx}. \quad . \quad . \quad (32)$$

The Reynolds Heat Transfer analogy enables us to introduce the wall friction factor $f=f(x)$.

i.e. write $$\frac{k}{\rho VC_p}=\frac{f}{2} \quad . \quad . \quad . \quad . \quad (33)$$

in (32) to obtain

$$\frac{dA}{dx}\left[1+\frac{n+1}{2(n-1)}\frac{f}{2\sin\phi}\left(\frac{T_w-T_{aw}}{T_0}\right)\right]$$

$$+\frac{A}{N}\left\{1+\frac{2N^2}{(N^2-1)(n-1)}\right\}\frac{dN}{dx}=0. \quad (34)$$

In the light of (34) it is clear that conditions at the throat will be identical with those in adiabatic flow. The throat velocity is determined completely by the term

$$1+\frac{2N^2}{(N^2-1)(n-1)}=0, \quad . \quad . \quad (35)$$

by which N_t is found to be,

$$N_t=\left(\frac{n-1}{n+1}\right)^{1/2}$$

$$=\left(\frac{\eta}{2\gamma/(\gamma-1)\ -\eta}\right)^{1/2} \quad . \quad . \quad . \quad . \quad (36)$$

In M notation the throat Mach number is

$$M_t=\left(\frac{n-1}{\gamma-1}\right)^{1/2} \quad . \quad . \quad . \quad (37)$$

With $\eta < 1$, it is obvious, since

$$\lim_{\eta\to 1} N_t=\left(\frac{\gamma-1}{\gamma+1}\right)^{1/2}=N^*, \quad . \quad . \quad (38)$$

the throat velocity will be subsonic.

The influences of heating or cooling are found by writing (34) as,

$$\frac{dN}{dx}=-\frac{N}{A}\left[\frac{1+\dfrac{n+1}{2(n-1)}\dfrac{f}{2\sin\phi}\left(\dfrac{T_w-T_{aw}}{T_0}\right)}{\left\{1+\dfrac{2N^2}{(1-n)(1-N^2)}\right\}}\right]\frac{dA}{dx} \quad . \quad (39)$$

In the convergent portion where $N^2<(n-1)/(n+1)$ the amount in curly brackets is positive and dA/dx is negative; thus it is seen heat addition ($T_w > T_{aw}$) causes the local reduced velocity to increase. On the other hand heat extraction and friction tend to counteract each other, depending on whether

$$\frac{T_w-T_{aw}}{T_0}\lessgtr\frac{2(n-1)}{(n+1)}\cdot\frac{2\sin\phi}{f} \quad . \quad . \quad (40)$$

If cooling is predominant the local reduced velocity decreases but if friction predominates the behaviour is the same as with heat addition. An inspection of the likely magnitudes of the terms in (40) show friction should always predominate.

In the divergent portion where $N^2>(n-1)/(n+1)$ the amount in curly brackets is negative and dA/dx is positive. We see heat addition causes N to increase irrespective of friction. Again heat extraction cannot produce a reduction in N unless it is predominant. As before, inspection of the terms in (40) lead us to conclude retardation due to cooling is impossible.

The above results are compatible with those obtained elsewhere[1, 2] using more general methods.

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Approximate Estimation of the Passage Vorticity in the Secondary Flow Behind A Cascade

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EXPRESSIONS for the secondary circulation behind a cascade are derived in Ref. 1. A simple derivation of the same results is given in Ref. 2. The secondary flows within the blade passages and their extensions downstream are determined by the "secondary passage circulation", Γ, given by

$$\Gamma=\frac{dU_1}{dz}\left[\frac{s}{2}\frac{\sin 2\alpha_1-\sin 2\alpha_2}{\cos\alpha_1}+\left\{\int\frac{dL_l}{q_l}-\int\frac{dL_u}{q_u}\right\}U_1\right] \quad . \quad . \quad (1a)$$

for a diffusing cascade, and

$$\Gamma=\frac{dU_1}{dz}\left[\frac{s}{2}\frac{\sin 2\alpha_2-\sin 2\alpha_1}{\cos\alpha_1}+\left\{\int\frac{dL_l}{q_l}-\int\frac{dL_u}{q_u}\right\}U_1\right] \quad . \quad . \quad (1b)$$

for an accelerating cascade,

where U_1 inlet velocity to cascade
z distance in spanwise direction
s blade pitch
α_1 inlet flow angle
α_2 outlet flow angle
L_l distance along lower side of aerofoil
L_u distance along upper side of aerofoil
q_l velocity along lower side of aerofoil
q_u velocity along upper side of aerofoil.

The secondary flow is due to the distortion as it passes through the cascade of the vortex filament in the inlet flow that represents the spanwise velocity variation dU_1/dz. The net streamwise component of the portion *cd* (Fig. 1)

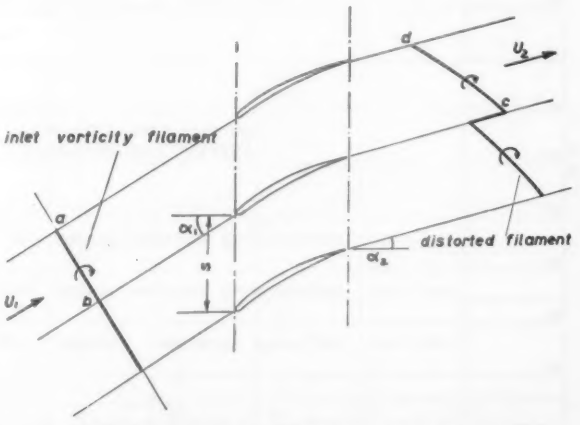

FIGURE 1. Passage of vortex filament through cascade.

Originally received 9th October 1959.
Revised 20th May 1960.

of the vortex filament forms the secondary passage circulation. The secondary passage circulation is equal to the sum total of the secondary passage vorticity across the passage. If the secondary passage vorticity ω is assumed to be distributed uniformly across the passage we can write

$$\Gamma = s \cos \alpha_2 \omega.$$

Squire and Winter[3] considering an impulse cascade gave a value for ω as

$$\omega = 2\varepsilon \frac{dU_1}{dz} = 2(\alpha_1 - \alpha_2)\frac{dU_1}{dz}$$

where ε is the deflection in radians of the stream by the cascade.

Using equation (1*a*) which applies to diffusing cascades (and similarly (1*b*) that applies to accelerating cascades)

$$\Gamma = s \cos \alpha_2 \omega = \frac{dU_1}{dz}\left[\frac{s}{2}\frac{\sin 2\alpha_1 - \sin 2\alpha_2}{\cos \alpha_1} + \left\{\int \frac{dL_l}{q_l} - \int \frac{dL_u}{q_u}\right\} U_1\right]. \quad . \quad (2)$$

The term $\left\{\int \frac{dL_l}{q_l} - \int \frac{dL_u}{q_u}\right\}$ represents the difference in time taken for a particle to traverse the lower and upper surfaces of the aerofoil. This quantity can be found by numerical integration if the velocity distribution round the aerofoil is known. The computation of the velocity distribution round an aerofoil in cascade is protracted and laborious. An approximate estimate of this quantity can, however, be made that will allow a rapid evaluation of the secondary vorticity.

Taking the aerofoils to be thin and represented by a distribution of vortices, one can consider the cascade to be a system of vortices superimposed on a uniform parallel flow U_m, where U_m is the vector mean velocity. The inlet and outlet velocities U_1 and U_2 are then the resultants of U_m and the induced velocities due to the system of vortices.

Taking the incremental velocity u due to the bound circulation to be constant over the aerofoil, the aerofoil velocity can be written as equal to $(U_m + u)$ on the upper surface and $(U_m - u)$ on the lower surface if the angle of attack is small. This will be the case at moderate values of lift coefficient. The angle of attack is the angle between the aerofoil chord and the vector mean velocity U_m. Assuming that the aerofoil is of small camber, the circulation K around it is given by $K = 2uc$, c being the aerofoil chord.

The lift on the aerofoil is given by

$$L = \rho U_m K$$
$$= \tfrac{1}{2}\rho U_m^2 c C_L.$$

This yields $u = \frac{1}{4} C_L U_m$.

The time taken by a particle to traverse the upper surface of the aerofoil is

$$\int \frac{dL_u}{q_u} = \frac{c}{U_m + u}$$

similarly

$$\int \frac{dL_l}{q_l} = \frac{c}{U_m - u}.$$

This gives $\left\{\int \frac{dL_l}{q_l} - \int \frac{dL_u}{q_u}\right\} = c\frac{2u}{U_m^2 - u^2}$

$$= c\frac{\frac{1}{2}C_L U_m}{U_m^2 - \frac{1}{16}C_L^2 U_m^2}$$

$$= \frac{c}{U_m}\left[\frac{8C_L}{16 - C_L^2}\right].$$

Substituting the above in equation (2) and making use of the fact that by continuity $U_1 \cos \alpha_1 = U_m \cos \alpha_m$:—

$$s \cos \alpha_2 \omega = \frac{dU_1}{dz}\left[\frac{s}{2}\frac{\sin 2\alpha_1 - \sin 2\alpha_2}{\cos \alpha_1} + \frac{c \cos \alpha_m}{\cos \alpha_1}\left\{\frac{8C_L}{16 - C_L^2}\right\}\right].$$

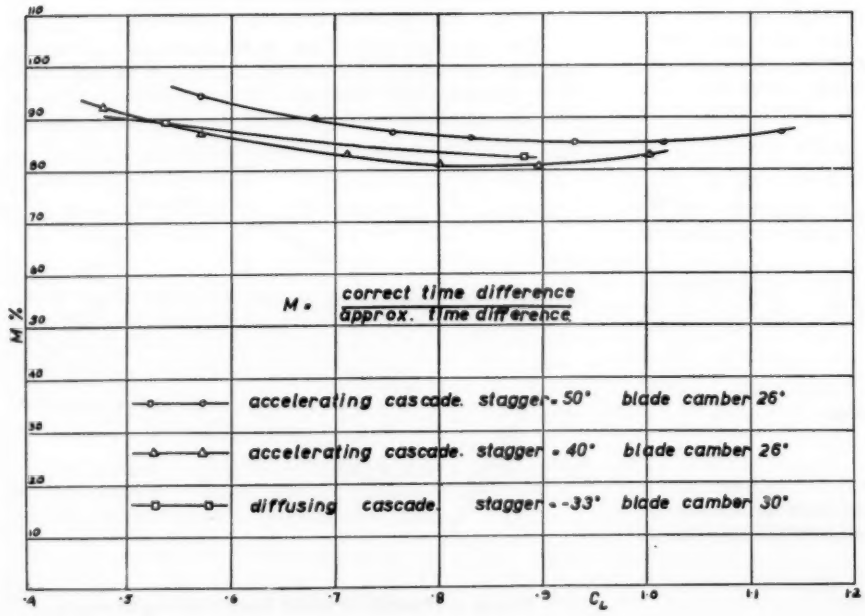
M %
M = correct time difference / approx. time difference
accelerating cascade. stagger = 50° blade camber 26°
accelerating cascade. stagger = 40° blade camber 26°
diffusing cascade. stagger = -33° blade camber 30°
C_L

FIGURE 2. Variation of M with lift coefficient.

This gives

$$\omega = \frac{dU_1}{dz}\frac{1}{\cos\alpha_2}\left[\frac{\sin 2\alpha_1 - \sin 2\alpha_2}{2\cos\alpha_1} + \frac{c}{s}\frac{\cos\alpha_m}{\cos\alpha_1}\left\{\frac{8C_L}{16-C_L^2}\right\}\right] \quad . \quad . \quad (3)$$

C_L is given by

$$C_L = 2\frac{s}{c}(\tan\alpha_1 - \tan\alpha_2)\cos\alpha_m.$$

Equation (3) requires only a knowledge of the lift coefficient to estimate the passage vorticity.

Alternatively if the incremental velocity is not taken to be uniform but to have a linear variation from $+2u$ at the leading edge to zero at the trailing edge over the upper surface, and from $-2u$ to zero over the lower surface, the velocities over the aerofoil can be written as:—

Velocity on the upper surface varies from $U_m + 2u$ at the leading edge to U_m at the trailing edge.

Velocity on the lower surface varies from $U_m - 2u$ at the leading edge to U_m at the trailing edge.

The velocity at any point on the aerofoil at a distance x from the leading edge along the chord is then

$$U_m \pm \frac{2u}{c}(c-x)$$

the positive sign applying to the upper surface and the negative sign applying to the lower surface.

The circulation round the aerofoil is

$$= \int_0^c \left\{U_m + \frac{2u}{c}(c-x)\right\} dx - \int_0^c \left\{U_m - \frac{2u}{c}(c-x)\right\} dx$$

$$= 2uc.$$

This gives, as before, $u = \frac{1}{2}C_L U_m$.

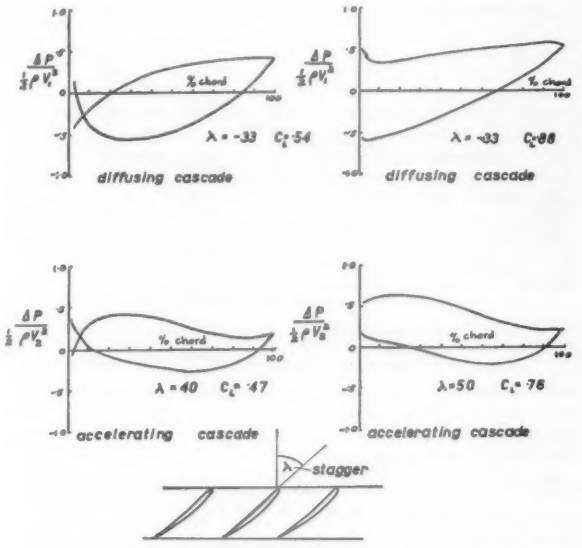

FIGURE 3. Typical cascade pressure distributions.

The time taken by a particle to traverse the upper surface of the aerofoil is

$$\int \frac{dL_u}{q_u} = \frac{c}{\text{mean velocity}} = \frac{c}{U_m + u}$$

similarly $\int \frac{dL_l}{q_l} = \frac{c}{U_m - u}$.

These values and the value of the circulation are the same as those obtained when the incremental velocities on the aerofoil are constant. Therefore we obtain the same value for ω as given in equation (3).

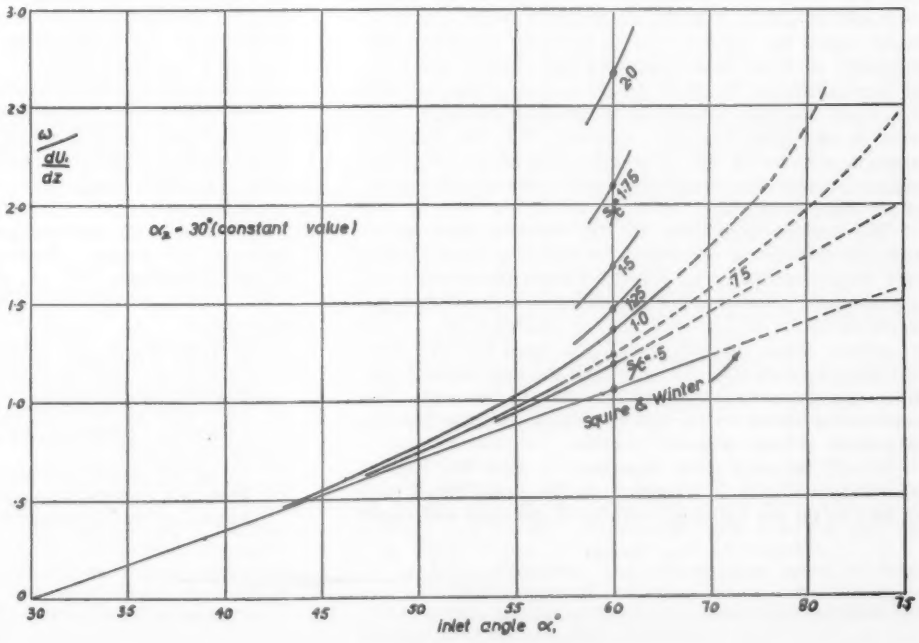

FIGURE 4. Variation of passage secondary vorticity with inlet angle for a fixed value of the outlet angle.

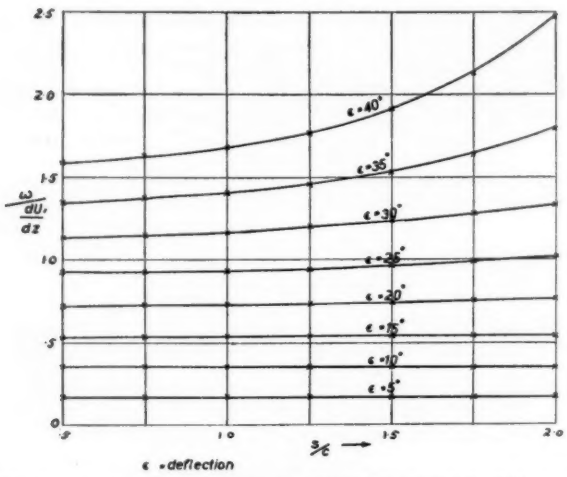

FIGURE 5. Variation of passage secondary vorticity with s/c ratio in an impulse cascade ($\alpha_1 = -\alpha_2$)

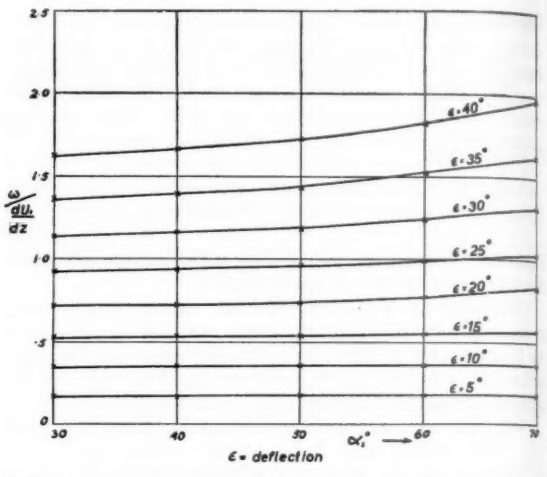

FIGURE 6. Variation of passage secondary vorticity with inlet angle at a fixed s/c ratio of 0·75.

Equation (3) may be used provided the velocity distribution over the aerofoil does not depart too strongly from the linear variation assumed. The validity of equation (3) depends on the degree of accuracy of the approximate estimation made here for the difference in time for a particle to traverse the lower and upper surfaces of the aerofoil. This approximate estimation has been compared in Fig. 2 to that obtained by a numerical integration of the potential velocity distribution for a number of cascade geometries obtained from unpublished data. Difficulties in the integration due to the existence of the stagnation point near the leading edge of the aerofoil were avoided by assuming that the velocities from the leading edge to a station $2\frac{1}{2}$ per cent chord behind it were uniform and equal to the velocity at that station. The pressure distributions for a sample of the cascade geometries computed are given in Fig. 3 as an indication of the variation of aerofoil velocities encountered in practice.

It will be seen that in the range of lift coefficients commonly used, the approximate method of computing the difference in time when traversing the aerofoil results in an over-estimation by about 15 per cent as compared with the more accurate numerical integration method. The error in estimating ω using equation (3) is less than the error in estimating the time difference since the latter appears in only the second term within the square bracket of the right hand side.

The cascade conditions for the velocity distributions used for calculating the graphs of Fig. 2 did not involve very large negative or positive incidences (measured from camber line). For example the diffusing cascade is at an incidence of 2° at $C_L = 0{\cdot}88$ and an incidence of $-7°$ at $C_L = 0{\cdot}54$. When the incidence had a large negative value (diffusing cascade $i = -17°$, $C_L = 0{\cdot}2$) the approximate time difference was under-estimated by about 15 per cent. This point is not shown on the figure. Similar under-estimation may occur at large positive incidence.

It will be seen from equation (3) that the passage secondary vorticity is dependent on the pitch/chord ratio as well as on the individual values of the inlet and outlet angles. That is, it is affected by the stagger of the cascade and not only by the deflection, the difference between the inlet and outlet angles. In Fig. 4 equation (3) has been compared with Squire and Winter's simple expression for the secondary vorticity for a fixed outlet angle of 30°. It is seen that for low pitch/chord ratios, say below 1·0, equation (3) and Squire and Winter's expression give almost identical values for the passage secondary vorticity for deflections below 15° and are in reasonable agreement for deflections between 15° and 25°. The effect of pitch/chord ratio is seen to increase with increasing pitch/chord ratio. The variation of passage vorticity with pitch chord ratio in an impulse cascade is shown in Fig. 5 which has also been plotted from expression (3). For low values of deflection pitch/chord ratio is seen to have little effect, while for higher values of deflection the passage secondary vorticity is seen to increase with pitch/chord ratio as in Fig. 4. The effect of stagger may be seen in Fig. 6. Here the pitch/chord ratio has been kept fixed at 0·75 and the inlet angle varied, the curves giving the passage secondary vorticity for various values of deflection. Here again the effect of stagger is marked only at high values of deflection.

The assumptions made in the derivation of equation (3) must be borne in mind and in spite of its limitations it can be taken that Figs. 4 to 6 show at least qualitatively the effect of pitch/chord ratio and stagger on the passage secondary vorticity. At low values of deflection both pitch/chord ratio and stagger have no noticeable effect, equation (3) giving values identical with Squire and Winter's expression for all practical purposes.

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2. SOUNDRANAYAGAM, S. (1957). The Secondary Flow Behind a Cascade. *Journal of the Aeronautical Sciences*, pp. 706-707, Sept. 1957.
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The Branches Page now reverts to chronological sequence with the first Branch to be formed in the 1930s, that of Gloucester and Cheltenham.

Before the advent of the Branch there existed the Gloucestershire Aircraft and Engineering Society, which was abandoned in favour of the formation of a Branch of the Royal Aeronautical Society.

The inaugural meeting of the Gloucester and Cheltenham Branch was held in the Cheltenham Technical College in November 1930, under the Chairmanship of Mr. H. P. Folland, then Chief Designer of the Gloster Aircraft Company, with Mr. L. W. Nethercott as Honorary Secretary. Mr. David W. Longdon, Managing Director of the Gloster Aircraft Company, was the first Branch President. Mr. Longdon and Mr. Folland had been President and Chairman respectively of the earlier Society.

The first lecture was delivered by the late Sir Richard Fairey, to a gathering of 180 enthusiasts; this meeting in the Cheltenham Public Library was an augury of success, to be followed by others at approximately monthly intervals, with eminent Lecturers from the Aircraft Industry.

Initially all lectures were given in the Cheltenham Technical College, but by popular demand this was later revised with monthly meetings held alternately at Cheltenham and Gloucester, also at the Technical College. The co-operation and indulgence of the two Principals, Mr. Ivamy (Cheltenham) and Dr. Watson (Gloucester) played a great part in helping to establish the Branch.

In these early days the Branch membership numbered about 80 with a lecture attendance of about 40. The Branch also organised courses for prospective ground engineers, most of the talks being given by members who were specialists in their subjects. Such efforts were rewarded by several members obtaining their licences, possibly a unique activity directly sponsored by a Branch.

Knowledge of some of the early lectures is uncertain, but it is interesting to note that Mr. G. H. Dowty (now Sir George), lectured on "Undercarriages" in Nov. 1933.

Sir George Dowty appears again in a 1934-35 lecture card, which records that Mr. T. O. M. Sopwith was President and also lists a lecture programme which is indicative of the age and the future, and is worthy of mention:—

Mr. H. P. Folland, Aircraft Design; Flt. Lt. P. W. S. Bulman, Test Flying; Mr. G. W. Allen, Aircraft Production; Mr. L. Radcliffe, England-Australia Air Race; Mr. G. H. Dowty, Retracting Undercarriages; Mr. W. W. Hackett, Tube Manipulation; Mr. W. C. Deveraux, High Duty Alloys: Senor J. de la Cierva, Autogiros; Mr. Nigel Norman, Airport Development; Mr. H. J. Pollard, Metal Construction; Dr. L. Aitchison, Magnesium Alloys; Major R. H. Mayo, Commercial Aircraft.

In 1933 the late Mr. F. B. Ford became Secretary with Mr. Folland remaining as Chairman and in 1937 Mr. W. G. Carter became President.

Then came the war and activities became dormant; but on the cessation of hostilities, and with a gentle shove from the Parent Society the Branch came out of hibernation. The primary moves to this end were made by Mr. Ford but he was handicapped by ill health and after his untimely death his work was carried on by Mr. J. F. Cuss, who has now been Chairman for several years. Under the chairmanship of Mr. W. G. Carter a Special General Meeting took place in September 1946, and the Branch was once again under way. The late Mr. H. L. Milner was elected Chairman, Mr. J. F. Cuss, Hon. Secretary and Mr. J. R. Redman, Hon Treasurer, with a supporting committee representative of the local firms engaged in the Aircraft Industry, and from the Gloucester and Cheltenham Technical Colleges.

The Branch held its 21st Anniversary in 1951 with a growing membership of 334 members, including 107 parent society members and six Honorary members. The occasion was marked by the issue of a Souvenir Brochure recording the histories of the Society, the Branch and supporting firms. At the Branch dinner 240 members were the guests of the Branch President, Mr. G. H. Dowty, with Major G. P. Bulman, President of the Society and Captain J. Laurence Pritchard, Secretary, adding distinction to a distinguished gathering.

Since its reconstitution the Branch has grown apace both in membership and activity, and current records reveal that membership stands at 406, inclusive of 122 parent society members. Peak membership was reached in 1955 with 480 members. The present fall is felt to be due to the appreciable reduction in personnel employed in the Aircraft Industry in the area served by the Branch, but on the whole the Branch has done well in avoiding a bigger drop in membership.

During the latter part of the 1949-50 session the Branch secured accommodation of a nature to be envied by any other Branch in the country; in Gloucester, the Wheatstone Hall, which is within the building of the old Technical College, while in Cheltenham the search for a more suitable Hall was rewarded by the discovery of the lecture hall of St. Mary's College. Committee meetings are held in the Conference Room at Dowty Rotol Limited, an arrangement for which the Committee would here express their gratitude.

The activities of the Branch are manifold and this page can only itemise the types of function. There are Branch lectures, area lectures, parent society lectures, visits by Presidents (Major Bulman, Major Halford, Sir Sidney Camm, N. E. Rowe) and Secretaries (Captain J. Laurence Pritchard and Dr. Ballantyne), visits to and from other Branches, the Barnwell Lectures at Bristol, the annual visit and lectures at Hereford, visits to Industry, the Garden Party, the S.B.A.C. show, dinners, dances, joint meetings with the Western Branch of the Institution of Mechanical Engineers, the Institute of Instrument Technology, and the Gloucester Engineering Society.

There have been approximately eight lectures per session, and of their standard this page can only refer to the recent Annual Report of the Honorary Secretary, Mr. C. E. Hutt:—"It is usual in the Report to select the outstanding lecture of the session but this is difficult since after at least four of the meetings people were heard to remark—'The best lecture we've ever had'."

Not quite so encouraging is the N. E. Rowe Medal Competition, for which awards the Branch offers annually two awards of £5 each for the best papers written by young members of the Branch. The number of candidates has not been overwhelming; however, the Committee hopes that perhaps this report will stir the bashful and lethargic into activity. This is a problem common to most Branches: perhaps a prize of some flying hours with the local Flying Club is the kind of incentive now required.

In addition to the usual Officers, and because of the large area served by the Branch which makes it impractical for the Officers and Committee members to maintain direct contact with all the members, Corresponding members have been co-opted. They are responsible for circulating notices, collecting monies and providing general liaison.

The Branch is proud to be one of the oldest branches of the Society, and has a modest satisfaction in its membership, and cordial relationships with Industry and the civic dignitaries of Gloucester and Cheltenham.

In fact Gloucester and Cheltenham seem to have exceeded their terms of reference, which were merely to "further that species of knowledge which distinguishes the Profession of Aeronautics."—G.W-W.

Graduates' and Students' Section

A Woman's View of Vacation Training

It is generally accepted nowadays that the most suitable training for a professional engineer consists of a combination of both study and practical experience, and it is for this reason that vacation training schemes are becoming such a common feature of the University courses. At this time many student members of the Society will recently have completed work under one of these schemes and it would be interesting and possibly helpful to other members to read comments on the training received.

It has been my experience that boredom is the arch-enemy, due mainly to the trainee being under-worked or given work which is monotonous—especially to one trained to think. It is appreciated that a novice cannot be entrusted with responsible work involving costly machines and materials and that in the eight weeks of the training period little real skill can be acquired, but there is surely some compromise between this limited manual ability and enforced idleness. Students frequently do acquire a reputation for idleness and yet this is contradicted by their own assertions that they would rather be kept busy. Since they are only available for a short period of time they cannot become integrated members of a working team and their labour is to a large extent superfluous.

The argument is advanced that a vacation trainee would be better employed in a drawing office, where the kind of work is more akin to that which will ultimately be undertaken, and that time spent in "tin-bashing" is of little or no use. This lends itself to the criticism that in order to design competently it is necessary to have at least some knowledge of the materials being used and this knowledge is best obtained by first-hand experience. Of course, it is debatable whether such knowledge can be obtained in such a short time and there are some who assert that a year on the factory floor is needed, preferably before going up to University. This was borne out by a recent survey conducted by this section and reported on this page, which showed quite clearly that many firms in fact prefer the sandwich courses to vacation and post-graduate training.

Few people would disagree that technical knowledge is only one of the things gained from vacation training: one learns, or can learn if sufficiently interested, much about factory practices, the structure of industry in general, and a great deal about people who are essentially dissimilar from one's fellow students. Such knowledge is undoubtedly valuable as part of a broader education but could be equally well acquired from work other than engineering. In view of this it is difficult to assess vacation training schemes as a useful addition to a degree course. Further comments regarding members' own experiences and comments are welcomed.—(Miss) G.M.H.

In Search of Employment

As another University year begins it is perhaps appropriate to recall that for many student members of the Section a decision regarding future employment must soon be made. In the June and July Section pages the Industry's view on Recruitment was presented and it is now intended briefly to present the approach of one individual to the task of obtaining employment.

Experience of the Industry was limited to two periods of vacation training spent mainly in learning the finer arts of drilling holes and riveting panels, and as the demand for graduates was rumoured to have fallen considerably it was decided to spread the net of enquiry as wide as possible. Early in the New Year—approximately six months before the termination of the University year—a large number of letters were written to firms who were likely to be able to offer employment primarily connected with Flight Testing or in the Projects Office, although no attempt was made to correlate these enquiries with advertisements in the aeronautical and daily press. First results were disappointing, consisting mainly of invitations to apply again when final results were available, notification that a further approach should be made to a representative of the firm concerned when he visited the University and flat refusals. Eventually arrangements were made to visit twelve firms during the Easter vacation, although only five of these resulted from interviews at the University.

Nine of these visits were made and naturally involved considerable travel. All the firms concerned were extremely generous in their attitude to travelling expenses and allowed wide latitude in the choice of interview date.

Interviewing techniques varied enormously from a ten-minute chat with a single individual (this following a 200 mile train journey) to an oral examination by a panel of aerodynamicists followed by a complete tour of the factory. Strangely enough the former case resulted in the offer of a job and one can only conclude that the interviewer had had some success with this technique at an earlier date. Although not interested in a Graduate Apprenticeship some endeavour was made to discover whether the interviewers regarded this training as essential to sound design and whether lack of this training would be detrimental to progress, *i.e.* promotion. There was almost complete accord that in the particular case of the individual who had completed a period of military service before commencing the degree course, a period of two years undergoing further training was not desirable, and this omission was not likely to affect a future career in the Industry. Whether this generalisation can be applied to all graduates is a matter for conjecture.

Of the nine firms visited two indicated almost two months later that they could offer no suitable employment, one did not bother to make any further comment, yet another did not make an offer for six weeks and then suddenly requested attendance for a further interview in another department. Only one firm made a definite offer during the interview while the other four all confirmed that they were prepared to offer positions soon after the interview. The salaries concerned were very similar and did not vary by more than £50 a year.

Link With the Student Branch of the I.A.S.

As a result of a recent meeting between the Section's Chairman and the Director of Student Activities of the American Institute of Aeronautical Sciences it has been decided that the two Sections will in future work in close collaboration. This will take the form of an exchange of ideas, articles in each other's Journals and, if possible, a joint meeting similar to the Anglo-American Conference.

Annual Dance: Friday 25th November

The dance this year will be the last one to be held in the Library of the Society at 4 Hamilton Place, W.1, as future functions will be held in the new Lecture Theatre. Dancing will be, as usual, to the music of Hugh McCamley, and double tickets, which include free drink and refreshments, will against cost only 14s.

Your tickets may be obtained from your nearest Committee member or representative, or from Mr. W. G. Wilson, 107 Queen's Gate, S.W.7. *Cheques and Postal Orders should be made payable to Graduates' and Students' Section, Royal Aeronautical Society.*

Future Visits

The following visits have been arranged:—

Royal Aircraft Establishment, Farnborough (all-day), Wednesday 12th October.

Guinness Brewery, Park Royal (morning), Saturday 5th November.

Lotus Components, Cheshunt (morning), Saturday 19th November.

Associated-Rediffusion TV Studios, Wembley Park (evening), Tuesday 6th December.

Applications for these visits should be made to the Hon. Visits Secretary: N. R. Craddock, 5 Oxleay Road, Harrow, Middlesex (Tel.: Pinner 3633) *at least a fortnight before the date of the visit.*

THE LIBRARY

Reviews

THE AEROPLANE. An historical survey of its origins and development. *Charles H. Gibbs-Smith. H.M.S.O. London, 1960. 375 pp. 22 illustrated plates. 35s.*

Octave Chanute, that great American engineer and gliding experimenter of the nineteenth century, who did so much over the years to help and encourage the Wright Brothers, published in New York in 1894 his book *Progress in Flying Machines.* In it he detailed and commented upon all that was known about flying machines at that time. It was a remarkable appreciation of the flying machine and became a mine of information for all experimenters, including the Wright Brothers to whom a copy was recommended for first reading by the Smithsonian Institution in 1899, before they had begun their gliding experiments.

It is not unreasonable to say that Mr. Gibbs-Smith's historical survey of the origins and development of *The Aeroplane,* now published on behalf of the Science Museum of London, will rank very high in aeronautical literature, and take its place in the history of flight as Chanute's great classic has done, though the present author's task has been far the greater. This is not only the work of a dedicated historian, but one which shows constant, patient research and inquiry over many years of incredible, almost fantastic progress in flying machines.

Mr. Gibbs-Smith has broken with the traditions of the handbooks of the Science Museum and, indeed, with much of the traditional way of writing history. He has a lively personal style which will appeal to a larger public than just those who visit the National Aeronautical Collection. This handbook is an entirely new conception and one of great value to the history of aviation. Mr. Gibbs-Smith often tells us as much about the personalities of the early pioneers as he does about their ideas and practical achievements. This is a more important book, better, indeed, in the reviewer's opinion, than Mr. Gibbs-Smith's *History of Flying* published in 1953, for much air has flowed over the aeroplane wings since that anniversary year.

The book is divided into three main sections, the first a straightforward history of the development of the aeroplane; the second an interlude of quotations from pioneers and writers on flight; and the third a commentary on the development of the aeroplane with an Addenda and Corrigenda of some thirty pages to bring information up to date.

These last minute additions and corrections are most valuable and interesting. They are the direct results of meticulous research and inquiry. Mr. Gibbs-Smith has cast his aerial net widely and caught many interesting flying fish, which has enabled him to correct much that has been misleading in the superficial aeronautical histories of the past forty years. New light has been thrown on the work and achievements of such pioneers as Sir George Cayley, Horatio Phillips, Otto Lilienthal, Octave Chanute, the early French pioneers, as well as many of the later actual flyers. Claims made by many as having flown before the Wright Brothers are critically examined and in every case shown to be completely without justification.

If Mr. Gibbs-Smith can be challenged on some of his conclusions—and the reviewer is one who does not accept that everything in the Gibbs-Smithsonian air is lovely—it will be largely because he has allowed his enthusiasm to run away with him sometimes—a fault, nevertheless on the right side. When all is said and written, the great value of the present history will be in the material which has been provided for future historians.

One aspect of aeronautics which is so well brought out is the astounding foresight of those nineteenth century pioneers who saw so clearly the shape of things to come. I shall only take two extracts from this history, for printing space in the 1960s is almost as expensive as supersonic air liners will be in the 1970s.

"The whole problem is confined within these limits, *viz.*—To make a surface support a given weight by the application of power to the resistance of the air," wrote Sir George Cayley in 1809, and, seven years later, "An uninterrupted navigable ocean that comes to the threshold of every man's door ought not to be neglected as a source of human gratification and advantage."

This giant among pioneers discussed the power, the stability, wing loading, streamlining, and fundamental principles of heavier-than-air flight, and carried out practical aerodynamic and engine researches in order to give his ideas substance; he published his designs for all to see. He was the first to try model gliders, and the first to try out a fully manned glider and to publish his astonishing conception of the convertiplane—the V.T.O.L. which had to wait over a century before becoming a reality.

The other example is the work of that great French pioneer Alphonse Pénaud, who was a disciple of Cayley and did so much himself to advance Cayley's ideas. He was rightly declared by Charles Dollfus, the world famous aeronautical historian, as having left behind him an achievement "entièrement marquée du genie."

As Cayley dominated the aeronautical scene from 1809 to 1857, so Pénaud did the French scene in the 1870s. In 1876 he took out a patent for a full-size amphibious monoplane.

"It incorporated all his ideas for the practical aeroplane of the future, including dihedral setting of the wings; rear elevators; fixed vertical fin; vertical rudder; single control column—prophetically—for combined working of elevators and rudder; glass-domed cockpit; retractable undercarriage with rubber or compressed air shock absorbers; tail skid; wing-tip floats; double surface wings of wood or metal."

These were only two of the men of vision of the future of flying, and this is the book where you can read about them all and read that grandfather and great-grandfather were not such fools after all.

Her Majesty's Stationery Office has surpassed itself in the format of this great book. Mr. Gibbs-Smith deserves it and the Science Museum are to be congratulated on a Handbook which will soon go out of print.—J. LAURENCE PRITCHARD.

ADVANCES IN SPACE SCIENCE, Volume I. *Fred. I. Ordway (Editor). Academic Press, New York and London, 1959. 412 pp. Illustrated. 86s.*

This beautifully produced volume contains seven contributions:— Interplanetary Rocket Trajectories by D. F. Lawden (Univ. of Canterbury, N.Z.). Interplanetary Communications (Radio) by J. R. Pierce and C. C. Cutler (Bell Telephone Labs.). Power Supplies for Orbital and Space Vehicles by J. H. Huth (Rand Corporation). Manned Space Cabin Systems by E. B. Konecci (Douglas Aircraft Co.). Radiation and Man in Space by H. J. Schaefer (U.S.N. School of Aviation Medicine). Nutrition in Space Flight by R. G. Tischer (Mississippi State Univ.).

A Decimal Classification System for Astronautics by H. H. Koelle (A.B.M.A., now N.A.S.A.).

These titles make the coverage clear, and the authors' names and affiliations guarantee sound and comprehensive treatment within the permitted framework. The papers include good bibliographies.

There is no doubt that this is a useful reference work, and there is every reason to expect the further volumes in the series to live up to the promise of this first one. In his foreword, the Editor states that two more are already in preparation; it is intended to cover the whole field of astronautics, which of course embraces almost (if not quite) the entire range of disciplines known to science and technology. Perhaps some future edition, or similar work, will even need a paper on Martian archaeology!

One might perhaps criticise the editor for not choosing a more convenient grouping of subjects. Some potential purchasers might welcome a paper on cosmic rays along with two others on space medicine, but resent the inclusion of a highly-mathematical treatment of orbital theory, and discussions of space radio equipment and its electrical power supply. However, it is probable that poor Mr. Ordway was at the mercy of authors who found it difficult to deliver MS. on time, or perhaps of publishers who were anxious to sell the whole series of volumes—which they deserve to do.—A. V. CLEAVER.

ADVANCED AERO ENGINE TESTING. *A. W. Morley and Jean Fabri (Editors). Pergamon Press, 1959. 298 pp. Illustrated. 63s.*

This book is a collection of the papers presented at the joint meeting of the Agard Combustion and Propulsion Panel and the Wind Tunnel and Model Testing Panel at Copenhagen in October, 1958, and is in three parts. The first part (pp. 3-156) comprises four papers on Engine Test Facilities, the second part (pp. 159-259) has five papers dealing with Engine Component Testing, and the third part (pp. 273-290) contains one paper on Flight Test Problems.

Since a total of sixteen authors were involved in producing the ten papers, it is difficult to generalise on the standard of presentation, but most of the papers are clearly presented and straightforward considering the wide range and advanced state of the subjects treated. An exception is the paper on O.N.E.R.A. Modane Wind Tunnel which, being in French, will be wasted on the majority of British technical readers. The book is clearly printed on sturdy paper and is strongly bound.

Presumably the editors feel that this collection of papers will present a fairly complete guide to the general problem of engine testing and development, in addition to providing detailed authoritative treatment of some of the more important problems currently facing the industry. In this it is likely to succeed provided that the reader is stimulated to provide for himself the perspective into which the three parts of the book should fall.

In achieving this sense of perspective, the reader would be well advised to concentrate initially on Manganiello's paper in Part 1 entitled "Propulsion System Problems Investigated in Wind Tunnels and Altitude Test Chamber Facilities," together with the Part 3 paper by R. E. Pryor on "Flight Test Development of Supersonic Engines". In these, Manganiello presents a lucid general appreciation of the types of problem most usefully tackled in altitude test chambers, and Pryor indicates his view of the extent and complexity of the pre-prototype flight testing likely to be needed on supersonic engine applications. The other three papers in Part 1 deal comprehensively with the types of altitude test facilities available, the methods by which these facilities have been used or adapted to meet the increasingly rigorous requirements, and some of the difficulties and limitations of the existing plants. In these papers it is interesting to note the stress laid on the effects on engine performance and operational stability of the distortion of air flow patterns caused by air intakes. This is perhaps the most important single problem associated with the modern breed of supersonic aircraft engines, and deserves this respectful treatment. It is a pity that no clear indication is given of the scope for research into the large difference in sensitivity to inlet-airflow-distortion of otherwise comparable compressors.

Part 2 presents the complementary piece of the engine development jigsaw, in dealing with the testing of components. In the main this section gives a comprehensive view of the methods, the equipment, and the special problems of component research and development. Special emphasis is rightly given to the pitfalls awaiting the unwary in translating component test data to the complete propulsion system, and to the difficulties encountered in correlating model and full scale component results.

Slightly out of place in this section of the book is the paper by Macioce on "The Further Application of Generalized Parameters to Turbojet Performance Relationships," but this short paper is to be commended to the "performance-minded" members of the industry.

Although this book might initially appear to be lacking in editorial "connecting-tissue" between the various papers, the authoritative knowledge contained in it and the thought-stimulation that it should provide make it worthy of a place on the bookshelf of any practising aero-engineer.—J. RANDALL.

THE PRACTICAL USE OF RADIO AIDS FOR PILOTS. *John A. Terras. Pitman, London, 1960. 67 pp. Diagrams. 12s. 6d.*

This book explains simply, and in not too technical language, how a pilot may use various radio navigational aids available in the United Kingdom.

Perhaps, in parts, this book oversimplifies the issues involved, not so much from the explanation point of view but from the practical application, either in reality or in a Link trainer.

The author explains in the preface that the book is intended for "student pilots" and the explanations are phrased accordingly. The student pilot is encouraged to carry a mental picture of his position relative to the aid, and to keep this picture up to date with a simple mental D.R., and subsequent information obtained during flight.

Mr. Terras has made every effort to assist the student in achieving this picture, although in the initial stages some difficulty may be experienced in putting textbook learning into practice. A good understanding of the principles set out in this book will give a student a sound basis upon which to build his practical experience.

The book covers many of the radio navigational aids in use today, from simple V.D.F. procedures to the more complicated V.O.R. technique. In each case basic rules are given which hold good, no matter if the pilot is flying a Chipmunk or a Comet.

A book such as this is an invaluable aid when starting out in the complex aviation world, or as a means of refreshing the memory of a more experienced pilot.

This book shows that by using a few simple basic rules a sound mental picture can be obtained of the aircraft's position relative to the aid, and that an intelligent estimation of where you are is preferable to a complicated calculation which may later prove to be wrong.—E. R. G. PARKER.

AIR TRAFFIC CONTROL. *C. D. Colchester. Marconi Wireless Telegraph Co. Ltd., Chelmsford. 100 pp. Illustrated. 17s. 6d.*

During the past few years there have been numerous studies made into, and papers presented on, the ever growing problems of air traffic control. This book is the collected

papers of such a study group, undertaken by Marconi Wireless Telegraph Co. Ltd. It presents some of the views and findings of the members of this group on various aspects of this vast problem, for the consideration of those whose work lies in the field of Air Traffic Control.

Bearing in mind the publishers of this book, the reader should not be surprised to find that predominance has very rightly been given to the electronic requirement and development of Air Traffic Control Systems.

Opening as it does with a very brief history of air traffic control, this book's main concern is with the requirements for civil A.T.C. and the standards called for by I.C.A.O. The first paper presented looks at the present system used by the controller to maintain the necessary separations, and we are offered the conclusion that the system is in a poor state of health, on two counts. Firstly, the disproportionate relationship between the clearance space that must be allowed by Air Traffic Control, and the size of each aircraft. Secondly, the almost impossible task that the controller has, to assimilate the positional information of each aircraft within his sphere of responsibility, and the forward estimating problem to see the conflictions before they occur.

We have, therefore, the subject matter for two further papers. In the first place the question of greater accuracy in navigation aids and the consequent reduction in the size of the block of air space that must be carried with the individual aircraft. In the second place the necessity for some form of electronic data handling equipment together with calculations and computers to enable the controller to obtain forward estimates of the relative position of aircraft under his control. Both these problems are discussed at length.

The strongest pointer to the future is contained in Chapter VI and deals with the question of how the controller uses the information once it is available. Especially interesting is a brief description of methods of feeding information direct from the data handling equipments to the face of the radar tubes, thereby integrating the flight progress strip and the radar echo.

This book is, as stated, a collection of papers on various, but by no means all, aspects of the control of air traffic. It tells no story, it does not attempt to sell anything, and it offers no overall solution to the problem. After careful study of the views expressed, however, the reader is left with the feeling that there are plenty of solutions available if only someone would state the question.—B. E. J. HEARD.

FIGHTER COMMAND. *Peter Wykeham. Putnam, London, 1960. 320 pp. Illustrated. 30s.*

The sub-title of this book, "A Study of Air Defence 1914-1960," is rather misleading because the author has, in fact, concentrated on the development of R.A.F. Fighter Command since its formation in 1936. The first chapter provides a brief historical review of the events in this country during the First World War and after which led up to the formation of Fighter Command, but no serious attempt is made to trace the complete history of the air defence of the United Kingdom before that most significant event. However, as a history of the R.A.F.'s most famous Command, this book is altogether admirable and, as a serving officer with a well-balanced background in the operational, staff and command roles, few people are better qualified to write it than Air Vice-Marshal Wykeham.

The account opens with an explanation of the organisational changes in the R.A.F. which led up to the formation of the new Command as successor to the previous Fighting Area formation. There follows an admirable brief sketch of the early technical developments in electronics which made possible the establishment of the "Thin green line" of the radar warning chain which became the basis of the United Kingdom's air defence in the later 1930s and which, by 1940, had given us the most sophisticated and effective air defence system in the World at that time. The key parts played by H. E. Wimperis and Sir Henry Tizard in inspiring these developments are properly emphasised.

The next steps were the formation of Fighter Command itself under Lord Dowding, the evolution of the Command's organisation and, in particular, of the chain of operational control with its Operations Room structure at Command, Groups and Sectors and its associated communications system which made it a coherent executive organism and linked it with its radar and Observer Corps sources of information. Surprisingly, in view of the over-riding importance of this development, there is no detailed account of how the Operations Room concept originated. Was it not evolved from the old Fighting Area organisation at Uxbridge?

Air Vice-Marshal Wykeham then explains the origins of the eight-gun monoplane fighter and shows how the Hurricane and Spitfire were conceived and developed at the right time to become the essential weapons which the new Command required.

On the foundations of this admirable pre-War review, we are then led forward into a more balanced and effective account of the activities of Fighter Command in the Battle of Britain and on through the War years, than has been published before. Day and night fighting receive their due attention and, while policy and the basic technical, strategic and tactical factors receive most attention, there is a sufficiently intimate and realistic account—obviously made more effective by the author's own first-hand experience as a fighter pilot—of some of the more notable highlights of the operational side of the Command's activities. This maintains the drama and prevents the reader from forgetting for a moment the practical end-product of all the work on the ground—the actual operation of the aircraft in contact with the enemy.

Particularly interesting is the author's analysis of the well-known difference of opinion which existed in 1940 between No. 11 and No. 12 Groups about the tactical use of fighter formations and his views on the justification for the offensive policy adopted after Lord Douglas succeeded Dowding. However, among questions about the R.A.F. often asked since the War, there is unfortunately, no explanation of why steps were not taken to ensure that the Aircraft Industry devoted that technical effort to development which might have resulted in the Spitfire being given the sort of long-range capability which proved so valuable later in the War with the American Mustangs, Thunderbolts and Lightnings.

The final two chapters consider the problems of the Command in the years since the War. The introduction of jet aircraft and the new attitude to air defence which has come with the strategy of the Deterrent is explained. Within the inevitably inhibiting limitations of security, we are also told something of how Britain's air defence organisation stands today. This is an outstanding book which will certainly become a standard work of reference.—PETER W. BROOKS.

AIRCRAFT AND MISSILE DESIGN AND MAINTENANCE HANDBOOK. *Charles A. Overbey. Macmillan, New York, 1960. 369 pp. Diagrams. 9.75 dollars.*

A writer of a manual of design and maintenance covering both aircraft and missiles in one volume is faced with the considerable problem either of dealing adequately with very few design aspects or very briefly with them all and giving references to other works. Mr. Overbey uses a mixture of each with not very happy results because while some subjects are expanded where they fall within his personal experience, other most important aspects are treated too briefly to be of value to a designer or engineer and he gives no references as to where to seek further information. The selection of subjects and tables appears to have been made at random and one is

left in doubt as to the aim of this book. Being an American publication, the standards and specifications printed are naturally all of U.S. origin and few are comparable to those used in Britain.

The book begins with standard data sheets which include useful charts on the properties and compatibility of propellants, fuels and oxidisers, but also unaccountably includes in the weights and measures table such things as rods, poles and perches, bushels and hogsheads. A chapter on electrics suffers from severe contraction with the result, for instance, that an important subject such as cable terminations is dealt with in 11 lines, a treatment which allows only very general statements. The most important section of the book deals with materials of construction and provides a useful guide to the application of the different classes of material and of the properties of U.S. types of aluminium alloys and steels but misses being sufficiently precise to allow a designer or engineer to apply the information to a particular problem. The subject of plastics covers 25 pages but more than half of these are given over to the use and repair of Perspex ("Plexiglas") and only six pages to structural plastics which are of much greater current interest in aircraft and missile engineering. Another of the longer chapters of the book is given to nuts, bolts and rivets and, while these small parts are just as important as any other part of an aircraft or missile (after all there is a whole R.A.E. report on the design of bolts), the chapter does little more than reprint a number of U.S. specifications and tables.

The book will mostly be useful to designers and engineers having associations with American aircraft and missiles who seek information on American standards and specifications but, while the average British reader will find useful tit-bits of information, he will find little of substance to help in the design and maintenance of aircraft and missiles.—F. G. TARRANT.

UNITS, DIMENSIONS AND DIMENSIONLESS NUMBERS. *D. C. Ipsen. McGraw-Hill, London, 1960. 236 pp. 50s. 6d.*

The aim of this book is to provide an understanding of the meaning of the units and dimensions that are assigned to physical variables. The book is intended as a supplementary text for courses on fluid mechanics and heat transfer. There are problems at the end of most chapters, and some solutions are given. The style tends to be rather "chatty" (in the opening pages it struck one reader as being far too elementary).

The first two chapters ("The Description of Physical Ideas" and "The Physical Nature of Units") are noteworthy for the complete absence of mathematics. In the next chapter the mathematical nature of units is discussed in a rather arithmetical manner. Some of the abstract linguistic arguments here will be rather hard for a beginner to grasp. Indeed, in several places, notably in the discussion of Newton's second law of motion, the reader is first asked to consider some solution, only to be told on the next page that "We do not make this choice, however." The equation (p. 33) $lb_f = g_0 lb_m$ is very confusing, as is the statement (p. 43) that "Reynolds number is a dimensional (surely "dimensionless") variable only if we give force the dimensions of mass times acceleration".

The slug is introduced, very grudgingly, on p. 66. (From the context one would think that only "space men" use it.) Earlier mention of this important unit would have helped the reader considerably.

The simplest method of dimensional analysis (by solving for the values of the indices of the dimensions in question) is not mentioned. The method given is rather confusing, and the beginner might well think that the final result is completely fortuitous.

In the last two chapters, the physical interpretation of some dimensionless numbers is given, together with a discussion of properties of geometrically dissimilar systems. Some diagrams showing experimental results would have been helpful here, but there is not a single diagram in the book.

I am unable to recommend this book to any class of reader.—A. W. BABISTER.

JAHRBUCH DER WISSENSCHAFTLICHEN GESELLSCHAFT FÜR LUFTFAHRT (W.G.L.) 1958. *H. Blenk (Editor). Vieweg, Braunschweig, 1959. 300 pp. Illustrated.*

This volume contains mainly the papers given at the Stuttgart conference, but, contrary to previous practice, some 25 per cent of the papers are represented by summaries only.

The topics generally are in the classical tradition of aerodynamics and aeronautical technology by reputable authorities in their respective fields. When one considers the contents of current aviation literature perhaps the topics which are *not* included in this work will by their absence best demonstrate the traditional nature of the subjects. There are no contributions on V.T.O.L. or S.T.O.L. aircraft, ground-effect machines, rocket-propulsion or the vagaries of the many strange convertiplanes or similar hybrids under development in many countries. There is one paper, in English, on the launching of large missiles (W. A. Fiedler). But, with these exceptions, a wide range of subjects is treated including methods of measuring flight trajectories (O. Weber), the manufacture of sailplane wings from plastic reinforced with glass-fibre (E. Ohlmer), some problems of airport construction (W. Treibel) and some problems arising in air-law (H. Achtnich). In addition there are the perennial topics of lifting-surface theory (K. Gersten, F. Kowalke and F. Wegener), relation of boundary layers to compression and expansion processes (E. Becker), measurements on, and losses in, turbine impellers and cascades (K. H. Grewe and J. Rehbach) and two papers on helicopters, one dealing with the use of low-pressure air jets for propulsion and control (G. Heidelberg).

There are 45 papers, each with English and German summaries and selected points from the discussions. Several papers have been—presumably more will be—published elsewhere or issued as DFL Reports.

The publishers state that the attendance at the Stuttgart Conference confirmed the need for an all-German conference, despite the number of international conferences on aviation held elsewhere during the year. The value of such a conference presumably is greatest to those attending it, since many of the papers will reach the general reader on aeronautical topics through technical and academic publications. The discussions are also of value in elucidating points.

This volume also contains information on the constitution of the W.G.L., its activities and awards for original work.—F. A. BLAKE.

BIRDS AND FISHES, THE STORY OF COASTAL COMMAND. *Sir Philip Joubert de la Ferté. Hutchinson, London, 1960. 224 pp. Illustrated. 25s.*

There is plenty of scope for a comprehensive history of Coastal Command and, indeed, also for one of naval aviation but—in spite of the claims made by the Publishers on the dust cover—this book does not really set out to be either of these. It is much more a discursive and informal account of the origins and early development of the Royal Naval Air Service, combined with the story of the "Coastal" element of the Royal Air Force from 1918 to the present day.

This curiously-named book is well-written as one would expect of Sir Philip Joubert and is also eminently readable, but this reviewer must confess to a certain prejudice against the approach to history which is inevitable with popular books of this type. Strictly speaking, it is neither history nor personal reminiscence but a mixture of the two. While it will entertain and provide what one fears is sometimes rather inconsequential reading for a great many people who have,

perhaps, some interest in this branch of British Aviation, it also sometimes conflicts with the true interests of properly digested history. The trouble is that there are dangers in recording history in a casual fashion without meticulous checking of all facts. This is particularly true when the author is a generally-accepted authority on his subject: he is all too liable to be taken as infallible by subsequent historical writers who fail to cross-check their sources of information and thus sow the seeds of permanent misinterpretations and misrecordings of the past.

Sir Philip Joubert has been helped in this latest book by a number of participants in the events recorded. Several of these have provided contributions which add to the interest of the story—although at times, perhaps, rather away from the main theme. Why, for example, is there a long digression about the activities of the R.A.F. in South Russia in 1919/20?

The best part of *Birds and Fishes* concerns the inter-War period which includes a quite comprehensive account of the historic R.A.F. flying boat cruises to remote parts of the World. Particularly interesting is a short account of the little-recorded trip of the seaplane tender Pegasus to the Far East in 1924/25.

The neglect from which Coastal Command suffered for many years as the "Cinderella" of the R.A.F. up to the outbreak of the Second World War is emphasised in this account. As Commander of Coastal Command before the War, in 1936-37, and again during the War, in 1941-43, Sir Philip was particularly well-placed to appreciate this. However, his attitude to torpedo-carrying aircraft—whose development suffered especially from the parsimony of the Treasury at this time—is less easy to understand. Speaking of the pre-War period, he pours cold water on the possibilities of the air-launched torpedo and clearly indicates his lack of faith in it. Yet later, when he gets to the War years, he rightly emphasises the outstanding success of the Strike Wings using torpedoes and, later, rockets and the reader is confirmed in the impression that much more could, in fact, have been achieved in this field earlier if use of the airborne torpedo had been more energetically sponsored down the years. Incidentally, it would be interesting to know the origin of the Torbeau—the torpedo-carrying Beaufighter. Sir Philip attributes it to some ingenious member of the Bristol Company's staff in June 1942. Curiously enough, however, according to a diary kept at the time, this reviewer himself suggested this particular use for the Beaufighter to a senior officer at the Air Ministry (Sir Richard Peck) on 14th February 1942 just after the Scharnhorst and Gneisenau had made their spectacular dash up the English Channel. Peck is believed to have subsequently passed on the idea to Bristols. Was this the beginning of the Torbeau or had somebody thought of it earlier?—PETER W. BROOKS.

POWERED FLIGHT. A series of talks in the External Services of the B.B.C., produced by Robert Symes-Schutzmann. *The British Broadcasting Corporation, London, 1960. 52 pp. Illustrated. 2s. 6d.*

An interesting group of six talks was broadcast during 1959 by the B.B.C. on the General Overseas Services in the series "English Talks for Asia." These were given by such pioneers of powered flight as Lord Brabazon and Sir Geoffrey de Havilland, and others famous for their contributions to the development of the aeroplane as a vehicle of war and of peace. These talks were recorded on tape and future historians will therefore gain valuable impressions of the personality of each. Complementary to these records, the B.B.C. has now published a transcript with a foreword by Lord Brabazon. This is an admirable and well-illustrated booklet. The text is largely reminiscent, and will serve as useful texture to enliven the dryness which tends to dull all kinds of history. Robert Symes-Schutzmann, the producer, has made a small but useful contribution towards making aeronautical history a little more digestible for the student.—A.S.C.L.

Additions to the Library

Advances in Space Science. F. I. Ordway (*Editor*). Academic Press, New York. 1960. 450 pp. Illustrated. $13. *To be reviewed.*

Aero-Space: Applied Thermodynamics Manual. Society of Automotive Engineers, New York. 1960. Varied pagination. $25. *Reference only.* This large and comprehensive volume superseding Aeronautical Information Reports AIR 22, 23, 24 and 25, has been prepared to provide a single convenient source of reference material in aero-thermodynamics, fluid dynamics, heat transfer and related system design. There are three main sections on Engineering Fundamentals, Thermo-Physical Properties and Application Engineering and these are subdivided further into conventional headings. The volume is loose-leaf to facilitate additions and corrections which are sent to those filling in an accompanying form.

Aero-Thermodynamics and Flow in Turbomachines. M. H. Vavra. Wiley, New York (Chapman and Hall, London). 1960. 609 pp. 116s. *To be reviewed.*

Battle of Britain, The. E. Bishop. George Allen and Unwin, London. 1960. 235 pp. Illustrated. 21s. *To be reviewed.*

Bristol Fashion. John Pudney. Putnam, London. 1960. 102 pp. Illustrated. 12s. 6d. *To be reviewed.*

Britain's Imperial Air Routes, 1918 to 1939. Robin Higham. G. T. Foulis, London. 1960. 407 pp. Illustrated. 42s. *To be reviewed.*

British Instruments, Directory and Buyers' Guide. Scientific Instrument Manufacturers' Association. United Science Press, London. 1960. 330 pp. 45s. An elaborate catalogue-cum-directory-cum-guide to the industry, now in its second edition. A four-language glossary is provided of the headings used in the index of products and other features are a classified index of products, a list of trade names and a list of consultants, engineers and installers of schemes.

Claude Grahame-White. Graham Wallace. Putnam, London. 1960. 256 pp. 35s. *To be reviewed.*

Dictionary of Aerospace. Frank Gaynor. Peter Owen, London. 1960. 260 pp. 35s. *To be reviewed.*

Elliptic Functions with Complex Arguments. F. M. Henderson. University of Michigan, Ann Arbor. 1960. 37 pp. Tables. $8. Tables and charts of the *sn-*, *cn-*, *dn-* and *E*-functions intended to fill the need for complex values of the elliptic functions that arises in connection with plane harmonic or "potential" problems, *i.e.* the mapping problems of hydrodynamics, heat conduction and electromagnetic theory. The charts can be read to slide-rule accuracy and the tables opposite them to four significant figures. Thus, quick rough values and a general idea of the function's behaviour can be obtained. An Introduction summarises enough of the theory of elliptic integral to make the tables and charts understandable and describes the construction of the charts and their application. The presentation of the black curves on a green grid is clear, but in some cases lack of precise registration detracts from their general appearance.

Go Gliding. Ann Welch and Gabor Denes. Faber and Faber, London. 1960. 111 pp. Illustrated. 30s. *To be reviewed.*

Hydraulic Oils. C. C. Wakefield and Co. Ltd. 1960. 74 pp. This interesting booklet gives a short historical background to the subject and then goes on to fundamental principles, hydraulic pumps and motors, components of circuits and finishes with characteristics and physical properties. It does not pretend to be ex-

haustive but is extremely clear and readable; suggestions for further reading are given. Bona fide inquirers can obtain copies from Wakefield-Dick Industrial Oils Ltd., Castrol House, Marylebone Road, London N.W.1.

Hydrogen Peroxide Data Manual. Laporte Chemicals Ltd., Luton. 1960. 80 pp. A spiral-bound handbook incorporating all data likely to be required by those employing hydrogen peroxide. Intended to be of interest principally to engineers and designers in the aircraft and allied industries; a further volume is to be provided for the chemical industry.

Infra-red Radiation. H. L. Hackforth. McGraw-Hill, New York. 1960. 303 pp. 77s. 6d. An introductory text on infra-red radiation, its basic principles and applications, for use in "junior college and university courses" and for general background in formation.

Proceeding of the Frontiers of Science and Engineering (a Symposium). Institute of the Aeronautical Sciences and University of California. I.A.S., New York. 1959. 132 pp. $5 and $10 (members and non-members). Fourteen papers covering such subjects as Astro-mechanics, Biomedicine, Cryogenics, Military Aircraft, Instrumentation and Inertial Systems and Nuclear Power. All authors are authorities in the field and a useful overall view of the American scene is given.

Sell's British Aviation 1960. Business Dictionaries Ltd., London. 1960. 221 pp. This reference book contains 10 pages more than its previous edition. The pattern remains much the same as before—alphabetical section, classified trades, trade names and marks and so on. One can understand the choice of French for a list of useful terms in translation but why Spanish—and no other language?

Strömungslehre. Vol. I. Hydro- und Aerostatik Bewegung der idealen Flüssigkeit. O. Tietjens. Springer, Berlin. 1960. 536 pp. Illustrated. DM.66. *To be reviewed.*

Weather Forecasting for Aeronautics. J. J. George. Academic Press, London. 1960. 673 pp. Diagrams. £5 7s. 6d. *To be reviewed.*

Wider Universe, The. Paul Couderc. Hutchinson, London. 1960. 128 pp. Illustrated. 10s. 6d., boards, 5s., paper. This book deals with the whole universe beyond our solar system, and gives fundamental information on such topics as the structure and rotation of galaxies, the distribution of starts, the extra-galactic nebulae, the absorption of light in interstellar space, and the expansion of the universe.

S.A.E. PREPRINTS
Summer Meeting, Chicago (5th-10th June 1960)

No.

178A A polyvinyl alcohol solution as a quenchant for the hardening of steels. P. E. Cary, *et al.*

178B New nitriding process for increased wear and fatigue resistance. J. H. Shoemaker and G. Bidigare.

178C Engineering convection in heat treat furnaces. J. Huebler.

179A Fuel cells: introduction. L. D. McGraw.

179B The U.S. Army research and development program on fuel cells. S. J. Magram and B. R. Stein.

179C A nitrosyl chloride solar regenerative fuel cell system. W. E. McKee, *et al.*

180A The Marvibond process — seven years experience. P. E. Roggi and C. E. Kiernan.

180B Production and application of vinyl-coated steel. G. H. Rendel.

180C A new approach to vinyl films on steel. W. G. Cryderman.

180D Fusion bond coatings—a new technique for plastic cladding metal. W. R. Pascoe.

181A Radioisotopes broaden the approach to machining studies. M. Paliobagis and E. J. Krabacher.

181B Design considerations for radiochemical laboratory in industry. L. C. Schwendiman.

181C The applications of radioisotopes in machining operations. J. H. Tolan.

185A Ablation cooling of missiles and satellites. E. R. G. Eckert.

185B Plasma propulsion. S. W. Kash.

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195A Effects of the support system and stylus radius on roughness measurement. F. W. Kabat and C. H. Good.

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60-84 A mathematical model for locating exit taxiways. R. Horonjeff, *et al.*

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60-89 Base flow characteristics of missiles with cluster-rocket exhausts. B. H. Goethert.

60-90 Free flight facilities and aerodynamic studies at Canadian Armament Research and Development Establishment. H. F. Waldron, *et al.*

60-91 Flutter flight testing—recently developed techniques in excitation and data reduction. G. Grimm and J. Philbrick.

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60-93 In-flight simulation of re-entry vehicle handling qualities. R. P. Harper.

Reports

AERODYNAMICS

BOUNDARY LAYER *see also* INTERNAL FLOW

An investigation at transonic speeds of the performance of various distributed roughness bands used to cause boundary-layer transition near the leading edge of a cropped delta half-wing. E. W. E. Rogers and I. M. Hall with an appendix—A roughness band technique and materials. C. J. Berry and J. F. G. Townsend. C.P. 481. 1960.—(1.1.2.3×1.10.2.2).

Pressure and boundary layer measurements on a tapered swept wing in flight. D. Hyde. C.o.A. Report 128. *March* 1960.
Pressure and boundary layer measurements were made in flight on a full scale swept half-wing mounted as a dorsal fin on the mid fuselage of an Avro Lancaster aircraft. A Reynolds number range of $0{\cdot}88\times10^6$ to $1{\cdot}86\times10^6$ per foot was available. The tapered wing had a semi-span of 102·5 in. and an aspect ratio of 2·87; the quarter chord sweep was 40° and the symmetrical section was R.A.E. 102, of 8 per cent thickness/chord ratio along wind.—(1.1.3.1×1.10.2.2).

Tests of an area suction flap on an N.A.C.A. 64*A*010 *airfoil at high subsonic speeds. D. W. Smith and J. H. Walker. N.A.S.A. T.N. D*-310. *May* 1960.
The lift and drag of an N.A.C.A. 64A010 aerofoil with a 30 per cent chord plain flap were measured, both with and without suction. The chordwise extent of perforated suction area downstream of the flap hinge line was varied. Data were obtained at a Reynolds number of $2{\cdot}9\times10^6$ for a range of Mach numbers from 0·70 to 0·84 with several different suction-area configurations.—(1.1.5.2×1.3.4×1.10.2.1).

Effect of leading-edge thickness on the flow over a flat plate at a Mach number of 5·7. *M. O. Creager. N.A.S.A. T.N. D*-313. *May* 1960.
The flow field over a flat plate with various leading edge thicknesses was surveyed for a free-stream Reynolds number of 20,000 per inch. Impact-probe and surface static pressures were measured for a range of leading edge thicknesses from 0·001 to 0·25 in.—(1.1.1.4).

Vibration and near-field sound of thin-walled cylinders caused by internal turbulent flow. P. F. R. Weyers. N.A.S.A. T.N. D-430. *June* 1960.
The investigation concerned noise produced by turbulent flow adjacent to a flexible wall. Measurements were made of the spectrum and intensity of the pressure field outside thin-walled Mylar cylinders containing turbulent pipe flow. The resulting spectra could be interpreted in relation to the elastic properties of the cylinders and the character of the turbulent fluctuations inside the flow. The effect of cylinder wall thickness on the spectrum and intensity of the pressure fluctuations was investigated.—(1.1.3.1×1.5.1.1×5.6).

A method for the prediction of the onset of buffeting and other separation effects from wind tunnel tests on rigid models. H. H. Pearcey. AGARD Report 223. *Oct.* 1958.
The method is based on the observation of the divergence that occurs in the variation of mean static pressure at the trailing edge of an aircraft wing at the critical stage in the development of boundary layer separation when its influence first spreads to the trailing edge and thereby to the overall flow. Certain special considerations apply for swept wings. The various flow changes that are considered are illustrated by schlieren photographs and described.—(1.1.4.2×1.6.3×1.10.2.2).

COMPRESSIBLE FLOW *see also* INTERNAL FLOW
THERMO-AERODYNAMICS
WINGS AND AEROFOILS
AIRCRAFT OPERATION

Effect of body perturbations on hypersonic flow over slender power law bodies. H. Mirels and P. R. Thornton. N.A.S.A. T.R. R-45. 1959.
Hypersonic slender-body theory, in the limit as the free-stream Mach number becomes infinite, is used to find the effect of slightly perturbing the surface of slender two-dimensional and axisymmetric power law bodies. The body perturbations are assumed to have a power law variation (with streamwise distance downstream of the nose of the body). Numerical results are presented for (1) the effect of boundary layer development on two-dimensional and axisymmetric bodies, (2) the effect of very small angles of attack (on two-dimensional bodies), and (3) the effect of blunting the nose of very slender wedges and cones.—(1.2.3.1).

A study of the simulation of flow with free-stream Mach number 1 *in a choked wind tunnel. J. R. Spreiter* et al. *N.A.S.A. T.R. R*-73. 1960.
The degree to which experimental results obtained under choking conditions in a wind tunnel with solid walls simulate those associated with an unbounded flow with a free-stream Mach number of unity is investigated for the cases of two-dimensional and axisymmetric flows.—(1.2.2×1.10.2.1×1.12.1.2).

Free-flight measurements of the transonic drag characteristics of low-fineness-ratio cylinders including stabilizing plates and flares and varying nose bluntness. J. H. Judd and G. E. Woodbury. N.A.S.A. T.N. D-361. *May* 1960.
Various blunt-nose bodies of revolution of low fineness ratio based on a right circular cylinder of fineness ratio 2·0 were tested in free flight to determine drag coefficients over a Mach number range from 0·6 to 1·2 and a range of Reynolds numbers per foot from $4{\cdot}0$ to $8{\cdot}3\times10^6$. A single stabilising plate at the front and rear, a 16·5° conical flare, various nose radii, and 16·5° truncated-cone nose fairings were tested.—(1.2.2×25.3).

An investigation of induced-pressure phenomena on axially symmetric, flow-alined, cylindrical models equipped with different nose shapes at free-stream Mach numbers from 15·6 *to* 21 *in helium. J. N. Mueller* et al. *N.A.S.A. T.N. D*-373. *May* 1960.
Induced-pressure-distribution studies were made in a 2 in. helium tunnel and the Langley 11 in. hypersonic tunnel on six nose shapes: a hemisphere, a 45° included-angle cone, a 90° included-angle cone, a hemispherically blunted 45° included-angle cone, a hemisphere modified by a 90° included-angle conicle tip, and a flat configuration. Pressures were measured on the models from 0 to 50 model diameters from the nose-cylinder juncture. Reynolds number effects were determined in the range $0{\cdot}062$ to $0{\cdot}75\times10^6$.—(1.2.3.2×1.6.1).

Reduction of minimum-drag problems in supersonic flow to two-dimensional potential problems by means of the combined flow field. M. E. Graham and P. A. Lagerstrom. Douglas Report S.M. 23901. *March* 1960.—(1.2.3.1×1.10.1.2).

The impingement of a supersonic jet on a flat plate. L. F. Henderson. A.R.L. Note M.E. 238. *Feb.* 1960.
A three inch diameter supersonic jet was arranged to impinge on a twelve inch diameter flat plate. The plate was set at various incidences and positions in the jet. Pressure measurements were made on the plate, and the shock wave system photographed at three jet Mach numbers.—(1.2.3.2×1.6.1).

An experimental investigation of the head-on collision of spherical shock waves. J. I. Glass and L. E. Heuckroth. U.T.I.A. Report 59. *May* 1960.
The spherical shock waves at the point of collision were relatively weak ($M<1{\cdot}5$). Optical techniques were used to record the properties of the flow. These included schlieren wave-speed records of the time-distance plane, instantaneous-spark shadowgraphs, and multi-spark schlieren photographs with equivalent framing rates up to 50,000 pictures per second. An analytical or numerical solution to this problem has not been obtained. However, it is possible to compare the experimentally measured shock wave velocities at the point of collision with planar theory.—(1.2.3.2).

CONTROLS *see also* BOUNDARY LAYER
STABILITY AND CONTROL
WINGS AND AEROFOILS

Lift generation on a circular cylinder by tangential blowing from surface slots. V. E. Lockwood. N.A.S.A. T.N. D-244. *May* 1960.
The results of an investigation on the generation of lift on a circular cylinder which had a fineness ratio 8 with a 2·5-diameter end plate are presented. The investigation was made to determine to what extent the lift and drag characteristics were influenced by slot number, slot combination, slot position, and blowing momentum coefficient.—(1.3.6×1.4×1.10.2.2).

FLUID DYNAMICS *see* CONTROLS
INTERNAL FLOW
WINGS AND AEROFOILS
TESTING AND INSTRUMENTS
AEROELASTICITY

INTERNAL FLOW *see also* BOUNDARY LAYER
WINGS AND AEROFOILS
HYDRODYNAMICS

Some tests on cascades of compressor blades fitted with vortex generators. R. Staniforth. C.P. 487. 1960.—(1.5.4.2×1.1.4.2).

A turbine nozzle cascade for cooling studies. Part II. Comparison between measured and predicted mean Nusselt numbers at the blade surface. R. I. Hodge. C.P. 493. 1960.
The condition of the boundary layer around a turbine nozzle blade profile in a two-dimensional cascade is described at various levels of gas flow Reynolds number and turbulence. Surface distributions of heat transfer coefficient are calculated for the near isothermal case, with laminar and turbulent boundary layers. *Ad hoc* experiments give the blade surface heat transfer coefficients when the boundary layer is separated over part of the convex side.—(1.5.4.3×34.3.4×1.1.0.1).

The cooling performance of two extruded-type air-cooled turbine nozzle blades. R. I. Hodge. C.P. 495. 1960.
A study has been made of the performance of two internally air-cooled turbine nozzle blades made from extruded ventilated sections of similar outside profile. Blade temperatures and coolant pressures were measured in cascade tests over a range of gas conditions and cooling-air proportions. The assessment of blade performance at relatively low temperatures demands high accuracy for subsequent conversion to engine operating conditions. Details of the test techniques developed for high accuracy are included.—(1.5.4.3×1.5.1.1×34.3.4).

A diagram for thermo gas-dynamic processes. O. Lutz. R.A.E. Lib. Trans. 889. *April* 1960.
The enthalpy-entropy (Mollier) diagram though suitable for flows through nozzles, is too complicated for more general thermo-gas-dynamic processes. In particular, isoplane processes (in cylindrical pipes), such as shocks or the effects of choking can scarcely be followed; the same applies to the process of mixing. Thermo-gas-dynamics require most explicitly a diagrammatic presentation in which such processes can be followed exactly; including the changes in molecular weight due to combustion. The basic ideas are developed for such a diagram which would apply to air and combustible gases as long as the dissociation can be neglected. The method used for presenting specific heat is that given by the author previously. A comparison with examples calculated with constant values of the specific heat shows considerable discrepancies between the results.—(1.5.1×1.2.3×1.9×34.1).

A preliminary study of ionic recombination of argon in wind tunnel nozzles. K. N. C. Bray and J. A. Wilson. U.S.A.A. Report 134. *Feb.* 1960.
The theory of the ideal ionising monatomic gas has been formulated, and equilibrium and frozen one-dimensional flow calculations have been performed for this gas. A rate equation for the case of Argon has been discussed, and this has been used in criteria for the flow to be near equilibrium and nearly frozen. Energy radiated as a result of two-body recombinations may be neglected.—(1.5.1.4×1.4×1.2.0.1).

LOADS *see also* BOUNDARY LAYER
STABILITY AND CONTROL
EXTRA-ATMOSPHERIC TECHNOLOGY
MATHEMATICS
COMPRESSIBLE FLOW
AEROELASTICITY

A wind tunnel investigation into the factors affecting the spanwise load distribution over the vertical tail surface of an aircraft having a wedge-type rear fuselage. K. F. S. Chard and J. Deakin. With a foreword and an appendix by A. R. Collar. C.P. 491. 1960.
A wind tunnel model of a typical low-speed, straight-winged aircraft, having a wedge-type rear fuselage, was designed for an investigation of the factors affecting the spanwise load distribution over the vertical tail with the aircraft in a yawed attitude. The ratios, three different cockpits, three tailplane positions and a movable rudder; but the tests described here are limited to two tailplane positions. A propeller was not fitted. The fin and rudder surfaces were fitted with orifices for pressure distribution tests. An approximate method is proposed for predicting the spanwise load distribution over the vertical tail in yaw, from a knowledge of the variation of direction and velocity of the air flow in the region of the vertical tail with this surface removed.—(1.6.1).

STABILITY AND CONTROL *see also* HELICOPTER AERODYNAMICS
TESTING AND INSTRUMENTS
FLIGHT TESTING

Tests on a 1/36 *scale model of the Vickers M.T.* 1000 *in the compressed air tunnel, N.P.L. C. J. W. Miles and R. C. Fox. C.P.* 485. 1960.
Measurements of lift, drag and pitching moments on a 1/36 scale model, up to a Reynolds number of 7 millions are described. The experiments covered the effect of flaps (30° and 50°), dive brakes (30° and 50°) and of two tail planes of different span at two angles of incidence (+2° and −2°) relative to the wing.—(1.8.2.2×1.3.4×1.10.2.2).

*Effect of flow incidence and Reynolds number on low-speed aerodynamic characteristics of several noncircular cylinders with applications to directional stability and spinning. E. C. Polhamus. N.A.S.A. T.R. R-*29. 1959.
Cylinders with several cross-sectional shapes (including squares having various corner radii, rectangles, and a triangle) were studied. Since the flow incidences correspond to combined angles of attack and sideslip in the crossflow plane of three-dimensional bodies, the two-dimensional side-force results appear to have strong implications with regard to directional stability at high angles of attack and these implications, along with those associated with spin characteristics, are briefly discussed.—(1.8.0.2×1.10.2.1).

Fixed-base simulation study of a pilot's ability to control a winged-satellite vehicle during high-drag variable-lift entries. J. M. Eggleston et al. *N.A.S.A. T.N. D-*228. *April* 1960.
A winged-satellite vehicle which enters the atmosphere at high (approaching 90°) angles of attack was simulated in five degrees of freedom by using a fixed-base simulator. The task of controlling the vehicle and the vehicle's trajectory during the entry was performed by a human pilot. Variations of the pilot's task, the static and dynamic stability, control effectiveness, and the effects of adverse coupling of aerodynamic control moments were investigated.—(1.8.0.1×5×8.2).

*Study of the aerodynamic forces and moments on bodies of revolution in combined pitching and yawing motions. M. Tobak and H. C. Lessing. N.A.S.A. T.N. D-*316. *May* 1960.
Significant errors are pointed out in the accepted practice of writing the aerodynamic forces and moments that act on a body of revolution during pitching and yawing motion. A more correct formulation is presented. This permits an explanation of certain types of motion observed experimentally which have been explainable previously only with the assumption of nonlinear aerodynamic characteristics.—(1.8.0.1).

Simulator motion effects on a pilot's ability to perform a precise longitudinal flying task. B. P. Brown et al. *N.A.S.A. T.N. D-*367. *May* 1960.
Tests have been made on a moving and a fixed simulator to determine the effects motion cues have on pilot's ability to execute control. Quantitative measurements were made with two widely separated stick-force gradients and over a very wide range of longitudinal stability conditions.—(1.8.2.1).

*Investigation of the low-subsonic flight characteristics of a model of an all-wing hypersonic boost-glide configuration having very high sweep. R. E. Shanks. N.A.S.A. T.N. D-*369. *June* 1960.
Flight tests were made over an angle-of-attack range from 15° to 30° with and without artificial roll damping added. Force tests were made at angles of attack from 0° to 32° to find static stability and control characteristics.—(1.8.0.2).

*A manual frequency sweep technique for the measurement of airplane frequency response. H. L. Crane. N.A.S.A. T.N. D-*375. *April* 1960.—(1.8.2×13.2×1.12.2).

*Wind-tunnel investigation of a small-scale model of an aerial vehicle supported by ducted fans. L. P. Parlett. N.A.S.A. T.N. D-*377. *May* 1960.
The longitudinal-stability and pitching-moment characteristics and the power requirements of a simplified model of an aerial vehicle supported by ducted fans have been investigated. The model had two ducted fans, both fixed with respect to the airframe with their axes of revolution vertical for hovering flight.—(1.8.2.2).

The longitudinal aerodynamic characteristics of a sweptback wing-body combination with and without end plates at Mach numbers from 0.40 *to* 0.93. *W. P. Henderson. N.A.S.A. T.N. D-*389, *May* 1960.
The effect of end plates on the longitudinal aerodynamic characteristics of a sweptback wing-body combination is presented for high subsonic speeds corresponding to a Reynolds number (based on the mean aerodynamic chord) of approximately 2.3×10^6. The wing had 45° sweepback of the quarter-chord line, aspect ratio 4, taper ratio 0·3, and N.A.C.A. 65A006 aerofoil sections parallel to the plane of symmetry, and was mounted near the rear of a body of revolution having a fineness ratio of approximately 8.—(1.8.1.2×1.10.2.2).

Measurements on the relation between magnitude and duration and on the rate of application of the control forces achieved by pilots in simulated manoeuvres. T. van Oosterom. AGARD Report 241. *May* 1959.
The tests included measurements of the maximum control forces which a pilot can exert at various positions of the controls with respect to the pilot's seat. The forces, which can be maintained during various periods of time, were determined with the controls in the optimum positions that result from the measurements of the maximum forces. Measurements were made on the rate of increase of the pedal forces.—(1.8.0.1× 1.6.2×4.1).

Force and pressure tests of an AGARD calibration model B at a Mach number of 8. *L. D. Kayser and C. R. Fitch. A.E.D.C.-T.N.-*60-34. *July*. 1960.
Body-wing and body-only configurations of the AGARD Calibration Model B were tested at a nominal Mach number of 8 and Reynolds numbers from 0.8 to 11.0×10^6 based on model length. Forces and moments for both configurations were obtained from internal, strain-gauge balance measurements. Also, force and moment coefficients for the body-only configuration were obtained by numerical integration of pressure distributions.—(1.8.0.2×1.12.1.3).

Supersonic flight measurements of normal force and centre of pressure position for a related series of winged bodies. I. A. B. Cartmel. W.R.E. Aust., T.N. S.A.D. 45. *Aug.* 1959.
Results of a programme of free flight aerodynamic experiments in which normal force translation derivatives and centres of pressure were investigated for a related series of wings fitted to a cone-cylinder body are presented. Results are presented for 7 rectangular plan forms for supersonic speeds below $M=1{\cdot}7$. —(1.8.2.2×1.10.2.2×1.12.2.×13.2).

THERMO-AERODYNAMICS *see also* INTERNAL FLOW

*Approximations for the thermodynamic and transport properties of high-temperature air. C. F. Hansen. N.A.S.A. T.R. R-*50. 1959.
Approximations are presented for the thermodynamic and transport properties of high-temperature air. Compressibility, enthalpy, entropy, the specific heats, the speed of sound, the coefficients of viscosity and thermal conductivity, and the Prandtl number for air are tabulated from 500° to 15,000°K over a range of pressure from 0·0001 to 100 atmospheres.—(1.9.1×1.2.3.1×34.1).

*A study of methods for simulating the atmospheric entry of vehicles with small-scale models. B. L. Swenson. N.A.S.A. T.N. D-*90. *April* 1960.
An analysis is presented for the motion and aerodynamic heating of both glide and ballistic vehicles during atmosphere entry. Simulation of the effects of heating on various heat shielding designs is considered. Similarity relations for the investigation of full-scale vehicles by testing small-scale models are developed.—(1.9.1×25.2).

An approximate treatment of laminar heat transfer coefficient and its application to the calculation of temperature of supersonic vehicles. K. Miura. Aero. Res. Inst. University Tokyo. Report 355. *May* 1960.—(1.9.1).

WINGS AND AEROFOILS *see also* BOUNDARY LAYER
COMPRESSIBLE FLOW
CONTROLS
STABILITY AND CONTROL
HELICOPTER AERODYNAMICS
TESTING AND INSTRUMENTS

Some measurements in the vortex flow generated by a sharp leading edge having 65° *sweep. N. C. Lambourne and D. W. Bryer. C.P.* 477. 1960.
Vortex flow which arises when separation occurs at a highly swept leading edge is considered. Measurements were made in the flow over flat plates at 15° incidence each having a sharp leading edge of 65° sweep. The pressure and velocity distributions both along the axis of the vortex and for one cross section of the flow are presented together with a preliminary discussion of their significance.—(1.10.2.2×1.4.4).

An extension of Multhopp's lifting surface theory. R. W. Simpson. C.o.A. Report 132. *May* 1960.
The subsonic lifting surface theory due to H. Multhopp has been extended to include a chordwise discontinuity in the slope of the lifting surface.—(1.10.1.2×1.3.0.1).

Wind tunnel tests of a circular wing with an annular nozzle in proximity to the ground. R. K. Greif et al. *N.A.S.A. T.N. D-*317. *May* 1960.
Exploratory tests were conducted to determine the effects of forward speed and ground proximity on the vertical thrust of an annular nozzle exhausting from the lower surface of a thin circular wing. Lift, drag, and pitching moment data are presented with nozzle air flow data over ranges of altitude, nozzle pressure ratio, free-stream dynamic pressure, and wing angle of attack. Pressure distributions on the wing lower surface and on the ground are also included.—(1.10.2.2×1.5.1.4).

*Effect of streamline contouring in the wing-fuselage juncture in combination with the supersonic area rule of a sweptback-wing-fuselage configuration of high fineness ratio. C. D. Trescot. N.A.S.A. T.N. D-*387. *May* 1960.
An investigation has been conducted in the Langley transonic blowdown tunnel at Mach numbers from about 0.67 to about 1.32 to compare two methods for reducing the pressure drag for a high-fineness-ratio sweptback-wing-body combination at $M=1.3$. One configuration was axisymmetrically indented according to the principles of the supersonic area rule and the other configuration used the streamline concept of shaping the wing-fuselage juncture with the same longitudinal area development as that of the supersonic area-rule configurations.—(1.10.2.2×1.2.0).

HELICOPTER AERODYNAMICS *see also* TESTING AND INSTRUMENTS
AIRCRAFT OPERATION
DESIGN AND CONSTRUCTION

Wind-tunnel study of the response in lift of a rotor to an increase in collective pitch in the case of vertical flight near the autorotative regime. J. Rebont et al. *N.A.S.A. T.T. F-*17. *April* 1960.
It has been shown by the calculations of a preceding note that the effect on the lift of a rotor due to an increase in the effective collective pitch, while in the course of steady descending vertical flight near the autorotative regime, depends essentially upon the speed of the pitch change. Experiment confirms the result.—(1.11.3×1.8.2.2).

Response of rotor lift to an increase in collective pitch in the case of descending flight, the regime of the rotor being near autorotation. J. Rebont et al. *N.A.S.A. T.T. F-*18. *April* 1960.
An elementary calculation inspired by the classic treatment for the steady state permits the determination of the induced velocity and the overall lift of the rotor as a function of the collective pitch for all values of the advance per turn. The nature of the lift response is shown to be essentially a function of the rate of pitch change.—(1.11.3×1.8.2.1).

*Ground effect for lifting rotors in forward flight. H. H. Heyson. N.A.S.A. T.N. D-*234. *May* 1960.—(1.11.3).

*A note on the mean value of induced velocity for a helicopter rotor. H. H. Heyson. N.A.S.A. T.N. D-*240. *May* 1960.—(1.11.3×29.9).

*Tables and charts for estimating stall effects on lifting-rotor characteristics. A Gessow and R. J. Tapscott. N.A.S.A. T.N. D-*243. *May* 1960.
Rotor characteristics were calculated by numerical methods for a rotor having rectangular blades with −80° of twist with the use of a representative set of aerofoil section lift and drag characteristics covering a 180° angle-of-attack range. Application of the information to various types of rotor calculations for use in estimating blade motion, performance, stability derivatives, and load factors of lifting rotors is discussed.—(1.11.3).

Compressibility effects on the hovering performance of a two-blade 10-foot-diameter helicopter rotor operating at tip Mach numbers up to 0.98. J. W. Jewel. N.A.S.A. T.N. D-245. April 1960.

Performance curves are presented for tip Mach numbers from 0.09 to 0.98 and disc loadings as high at 22 lb./ft.². Induced velocities 15 and 45 per cent of the radius beneath the rotor are given for the maximum disc loads for a representative range of tip Mach numbers. Sound-pressure levels measured at a point about 30 feet from the centre of rotation and on a radial line inclined 5° below the plane of rotation are included for all Mach numbers above 0.45 covered in the tests.—(1.11.3×29.1×29.9×5.6).

Flight measurements of the effects of blade out of track on the vibration levels on a tandem rotor helicopter. L. H. Ludi and J. E. Yeates. N.A.S.A. T.N. D-364. May 1960.

Results are presented which show how the vibration level changes because of one blade on the front rotor being out of track for a range of out-of-track values. Measurements of blade out of track relative to a master blade are shown for the front rotor as recorded by an electronic blade tracker. Blade-fuselage clearances for the front and rear rotor were measured during an abrupt manoeuvre. Calculations which enable the prediction of vibration due to an out-of-track blade in hover are discussed.—(1.11.3×2×3.9).

High-tip-speed static-thrust tests of a rotor having N.A.C.A. 63(215)A018 airfoil sections with and without vortex generators installed. J. P. Shivers. N.A.S.A. T.N. D-376. May 1960.

An investigation has been made on a rotor having N.A.C.A. 63(215)A018 aerofoil sections with and without vortex generators installed to determine the maximum mean lift coefficients at low tip Mach numbers and the compressibility effects at high tip Mach numbers. Data are presented for blade-tip Mach numbers from 0.27 to 0.76 and corresponding tip Reynolds numbers from 1.67 to 4.59×10⁶.—(1.11.3×1.10.2.1).

Normal component of induced velocity for entire field of a uniformly loaded lifting rotor with highly swept wake as determined by electromagnetic analog. W. Castles et al. *N.A.S.A. T.R. R-41. 1959.*

Values of the normal component of induced velocity throughout the entire field of a uniformly loaded rotor at high speed are presented in charts and tables. Many points were found by an electromagnetic analog; details are given.—(1.11.3).

TESTING AND INSTRUMENTS *see also* COMPRESSIBLE FLOW
STABILITY AND CONTROL
HYDRODYNAMICS

An experimental investigation of the effect of wind tunnel walls on the aerodynamic performance of a helicopter rotor. V. M. Ganzer and W. H. Rae. N.A.S.A. T.N. D-415. May 1960.

Experimental tests were made to determine the range of advance ratio and blade angle in which wind tunnel wall corrections as developed for wings might be used for helicopter rotors. Lift and drag coefficient data were corrected by standard wing-type wall corrections using the full span of the rotor as the vortex span and the area of the rotor disc as the wing area. Data from three test section sizes were compared to determine at which blade angles and advance ratios the wind tunnel wall corrections gave satisfactory agreement.—(1.12.1.1×1.11.3).

Determination of damping derivatives from free-oscillation tests of non-linear systems using energy relations. C. J. Welsh et al. *A.E.D.C.-T.N.-60-104. June 1960.*

An energy analysis of the damping of a linear oscillatory system has been made and extended to non-linear wind tunnel configurations tested over a large amplitude range. An approximate procedure for handling amplitude traces of non-linear configurations tested in wind tunnels by which equivalent viscous damping derivatives can be obtained is given.—(1.12.1.3×1.8.0.2).

Pressure probes in free molecule flow. K. R. Enkenhus et al. *U.T.I.A. Report 62. June 1959.*

The case where the mean free path is so large compared with the probe diameter that intermolecular collisions may be neglected is treated. This is the condition for free molecule flow. Theoretical expressions are given for the pressure measured in a flowing gas with an orifice probe and a long-tube pressure probe. Experimental investigations have been conducted using a low-density wind tunnel and a rotating-arm apparatus. Agreement between theory and experiment was quite satisfactory.—(1.12.5×1.4×32.2).

Slip flow testing techniques. G. J. Maslach and S. A. Schaaf. AGARDograph 39. July 1959.

Aerodynamic requirements for a wind tunnel capable of operating in the slip and transition flow regimes are presented. Methods developed are illustrated by various current flow systems which meet these requirements. Structural design and fabrication techniques for large dynamic vacuum systems are reviewed. Instrumentation unique to low density aerodynamic research is described. The use of a free-molecule probe is discussed.—(1.12.1.3).

AEROELASTICITY

See also AERODYNAMICS—HELICOPTER AERODYNAMICS
DESIGN AND CONSTRUCTION
HYDRODYNAMICS

Calculated responses of a large sweptwing airplane to continuous turbulence with flight-test comparisons. F. V. Bennett and K. G. Pratt. N.A.S.A. T.R. R-69. 1960.

Calculated responses of symmetrical aeroplane motions, wing deformations, and wing loads due to gusts are shown to compare favourably with available flight-test results. These calculated responses are based on random-process theory, five degrees of freedom, lifting-surface aerodynamics, and one-dimensional vertical turbulence. The extent to which various degrees of freedom contribute to the responses is examined and in this connection the relative effects of static and dynamic aeroelasticity are determined.—(2×1.6.3×1.4.2×13×33.1.1).

Experimental investigation of the effect of aspect ratio and Mach number on the flutter of cantilever wings. E. Widmayer et al. *N.A.S.A. T.N. D-229. April 1960.*

Models having aspect ratios ranging from 2 to 13 were tested at Mach numbers up to 0·92. No general attempt is made to correlate the data with three-dimensional flow theory, but an examination of the data is made on the basis of reference theoretical values obtained from the two-dimensional incompressible-flow theory.—(2×1.10.2.2).

On the nonlinear approach to the aeroelastic stability theory. H. G. Küssner. AGARD Report 246. April 1959.

The different causes for the structural nonlinearities on aircraft are discussed. A representation of nonlinear force-deflection diagrams of aircraft parts by complex Fourier analysis is given. An approximate method for the solution of nonlinear flutter equations is developed using systems of homogeneous linear equations. A special case, the harmonic balance, is compared with more accurate solutions.—(2×33.1.2).

AIRCRAFT

See also HYDRODYNAMICS
AIRCRAFT OPERATION
AERODYNAMICS—HELICOPTER AERODYNAMICS

Some human engineering aspects of several unconventional aircraft. V. K. Putnam. AGARD Report 244. May 1959.

Interest by the military services in the potential of relatively high speed (compared to helicopters) aircraft that have the capability of vertical take-off, has been sufficient to finance the development of experimental test beds of several types of V.T.O.L. aircraft. Several of these aircraft have been flown sufficiently to permit observations to be made on subjective, or human engineering characteristics such as control, noise, downwash effects, etc. These are discussed.—(3.12×4.2.1×5.1.5).

DESIGN AND CONSTRUCTION

See also AERODYNAMICS—STABILITY AND CONTROL
AIRCRAFT

Experimental investigation of spin-up friction coefficients on concrete and nonskid carrier-deck surfaces. W. B. Horne. N.A.S.A. T.N. D-214. April 1960.

A series of landing-impact tests was conducted with a carrier-type jet aeroplane main landing gear to obtain data on spin-up friction coefficients for both concrete and non-skid deck surfaces for tyre-inflation pressures of 260, 320, and 400 lb./in.².—(4.2.2.3×33.1.2×6.5).

Structural analysis of multi-hinged control surfaces. E. Kosko. N.R.C. Report LR-276. March 1960.

An elastic small-deflection analysis is presented of a control

surface supported on a structure by means of three or more hinges. Effects of sympathetic flexure, of local bracket flexibility and of angular deflection are taken into account. The existence is shown of an elastic hinge moment, quadratically dependent on the external loading. Application is illustrated by numerical examples.—(4.2.2.5×2×33.2.3.1×33.2.4.1.3).

Consideration of human factors in helicopter design. W. G. Matheny. A.G.A.R.D. Report 238. *May* 1959.
The human factor problem in helicopter design, mainly those factors affecting operation and control, are discussed. The stability of the vehicle and the display of information to the pilot to enable him to operate the aircraft under instrument conditions, are dealt with.—(4.4×4.2.1×5.1.5.1.11.2).

AIRCRAFT OPERATION

See also AERODYNAMICS—BOUNDARY LAYER
STABILITY AND CONTROL
HELICOPTER AERODYNAMICS
AIRCRAFT
DESIGN AND CONSTRUCTION
AVIATION MEDICINE

Longitudinal range control during the atmospheric phase of a manned satellite reentry. A. Assadourian and D. C. Cheatham. N.A.S.A. T.N. D-253. 1960.
The feasibility of guiding a manned satellite to some preselected destination, by making use of the pilot to control the trajectory, has been demonstrated. A fixed cockpit coupled with an analogue computer simulated a high-drag variable-lift class of re-entry vehicle. One method made use of typical ground-controlled approach procedures and the other of onboard navigational aids.—(5×18×26×25.1).

Helicopter-engine acceleration-time requirements based on pilot demand during recovery from landing flareouts. A. B. Connor. N.A.S.A. T.N. D-370. *May* 1960.
To provide information on response requirements of helicopter engines, flight measurements are presented showing the times used by pilots to accelerate an engine from low to full power in a manoeuvre considered to make the greatest demand on engine-response time.—(5×1.11.2×3.9).

Some aspects of shock-wave generation by supersonic airplanes. G. H. Jordan. AGARD Report 251. *Sept.* 1959.
Some experimental in-flight pressure surveys of the near field of two test aeroplanes are discussed with regard to the effects of distance, configuration, and Mach number. The far-field pressures are discussed, and the effect of some of the many variables that influence the strength of the flow field is illustrated. Damage caused to structures on the ground is mentioned. The effect of supersonic flow fields on other aircraft in the close vicinity of the supersonic aeroplane is described. —(5.6×13×1.2.3.2).

AIRPORTS

See DESIGN AND CONSTRUCTION

EXTRA-ATMOSPHERIC TECHNOLOGY

See also AERODYNAMICS—STABILITY AND CONTROL
AVIATION MEDICINE
ELECTRONICS
METEOROLOGY

Analysis of low-acceleration lifting entry from escape speed. F. C. Grant. N.A.S.A. T.N. D-249. *June* 1960.
Simple formulae are derived which yield approximations to the minimum loadings for steep entries. The general advantage of operation on the high-drag side of maximum lift-drag ratio is demonstrated analytically. The optimum character of modulation from maximum lift coefficient is shown.—(8.2×1.6.2).

Interim definitive orbit for the satellite 1958-*Gamma, Explorer-III. Goddard Space Flight Center. N.A.S.A. T.N. D*-356. *June* 1960.—(8.1).

Determination of the internal temperature in satellite 1959 *Alpha* (*Vanguard II*). *V. R. Simas* et al. *N.A.S.A. T.N. D*-357. *June* 1960.
Satellite 1959 Alpha was equipped so that accurate measurement of the minitrack beacon frequency (with the Doppler component removed) was sufficient to determine the satellite's internal temperature. To provide a precise measurement of this frequency a sensitive receiving system, utilising a highly stable but tunable first local oscillator and a noise-eliminating tracking filter, was developed. Considerable other information such as roll rate and rocket performance was obtained from the observations.—(8×18).

Telemetry code and calibrations for Satellite 1959 *IOTA* (*Explorer VII*). *I. L. Cherrick. N.A.S.A. T.N. D*-484. *May* 1960.
Material is limited to that necessary to decode and convert to basic measurements the data transmitted on the 19.992-Mc telemetry signal of Satellite 1959 Iota (Explorer VII). The interpretation of results is discussed only insofar as the individual experimenters have supplied comments in this regard.—(8×18×32.2).

A class of optimum trajectory problems in non-central gravitational fields. R. M. Licher. Douglas Report S.M.-23962. *May* 1960.—(8.2).

AVIATION MEDICINE

A restraint system enabling pilot control under moderately high acceleration in a varied acceleration field. H. A. Smedal et al. *N.A.S.A. T.N. D*-91. *May* 1960.
The pilot was subjected to varied, relatively high accelerations up to 7*g* from 2 to 5 mins. duration, in the vehicle simulator while he performed complex tracking problems. It was necessary to design a special restraint system which combined the use of a modified N.A.A.S. posterior mould or couch with an anterior restraint fabricated from nylon straps and nylon netting, and incorporated head and face supports.—(9×8.2).

Link trainer tests on simple modifications to the three pointer altimeter. D. J. Baines and J. R. Baxter. A.R.L. Note H.E. 6. *April* 1960.—(9×18×5.3).

ELECTRONICS

Some basic considerations of telemetry system design. H. J. Peake. N.A.S.A. T.N. D-355. *June* 1960.
A basic description of some of the main factors involved in the design of a telemetry system is presented. Variations of system parameters are given in tables and graphs, and are discussed separately so that a single element of a system, such as the gain of a parabolic antenna, may be considered. Illustrative examples of computations for a complete system are given. —(11×18.1×8.2).

FLIGHT TESTING

See also AERODYNAMICS—STABILITY AND CONTROL
AIRCRAFT OPERATION
AEROELASTICITY

Techniques used in a programme of free flight aerodynamic trials. J. A. B. Cartmel. W.R.E. Aust., T.N. S.A.D. 40. *May* 1959.
Some techniques that were used and developed during the course of a programme for the free flight measurement of the aerodynamic derivatives for a related series of wing-body test vehicles are discussed.—(13.2×1.8.0.2).

FUELS AND LUBRICANTS

See also MECHANICAL ENGINEERING

The force of friction and surface deformation. V. D. Evdokimov et al. *R.A.E. Lib. Trans.* 904. *June* 1960.
An investigation of the elastic deformation of sliding surfaces is described.—(14.2).

The scientific basis for the preparation of colloidal graphite lubricants. L. A. Feigin and I. B. Davidovskaya. R.A.E. Lib. Trans. 905. *June* 1960.
The effects of milling graphite under various conditions of environment are discussed in relation to the lubricating properties of colloidal dispersions prepared from it.—(14.3).

The effects of surface-active lubricants on resistance to shear during friction. I. S. Avetisyan and G. I. Epifanov. R.A.E. Lib. Trans. 906. *June* 1960.
Experiments to investigate the boundary lubricating properties of solid and liquid organic lubricants for various metal sliding combinations are described.—(14.3).

HYDRODYNAMICS

Visualization of secondary flow in the reservoirs of the slotted-wall working sections of the A.R.L. 12 *in. and* 30 *in. water tunnels. D. A. E. Leaver. C.P.* 483. 1960.—(17×1.12.1.3×1.5.1.4).

Theoretical determination of water loads on pitching hulls and shock-mounted hydro-skis. E. Schnitzer. N.A.S.A. T.N. D-392. May 1960.
A dynamic-camber theory is developed for determining the loads and motions of seaplanes with high length-beam ratios, shock-mounted hydro-skis, and other bodies impacting or planing on a water surface while undergoing pitching rotation. The effects of pitching rotation on longitudinal pressure distribution are shown.—(17.2×2×33.1.2).

Theory of the motion of a body with cavities partly filled with a liquid. D. E. Okhotsimskii. N.A.S.A. T.T. F-33. May 1960.
A derivation and discussion of forces associated with small motion of a right circular cylinder containing fluid with a free surface are presented. For impulsive motion, simple harmonic motion, and motion just beginning it is shown that the body of fluid possesses inertial characteristics similar to the mass, moment of inertia, and centre of mass of a rigid body. Suggestions are given for establishing the general equations of motion of the system.—(17.1×25.4×33.1.2×33.2.4×3.7).

INSTRUMENTS AND EQUIPMENT

See also AIRCRAFT OPERATION
EXTRA-ATMOSPHERIC TECHNOLOGY
AVIATION MEDICINE
ELECTRONICS
MECHANICAL ENGINEERING

Some notes on the possible application of thermoelectric devices to the generation of electric power. P. J. Bateman. C.P. 499. 1960.
When waste head is available in a convenient form, conversion to useful electrical power should be possible by means of thermoelectric devices which, fabricated from semi-conductor materials already developed, should give a power output per unit weight comparable with that of conventional small d.c. power sources.—(18.1×32.2.1).

MATERIALS

A correlation between rain erosion of perspex specimens in flight and on a ground rig. T. J. Methven and B. Fairhead. C.P. 496. 1960.
The amount of surface erosion on Perspex has been measured for specimens flown on an aircraft in rain and tested on a whirling arm ground rig in artificial rain. Specimens were compared at 400 knots and similar rain concentrations.—(21.3.3×24).

Application of rate-temperature parameters to tensile data for magnesium alloys and a relation between the Larson-Miller constant and the activation energy. C. R. Manning. N.A.S.A. T.N. D-172. May 1960.
The Larson-Miller and Dorn rate-temperature parameters were successfully applied to published data to take into account the effect of strain rate and temperature on tensile properties of six magnesium alloys. Values of the Larson-Miller constant and the activation energy used in the Dorn parameter were determined for each material. A relation between the values of the Larson-Miller constant and the activation energy was determined for magnesium and aluminium alloys.—(21.2.2).

The dependency of penetration on the momentum per unit area of the impacting projectile and the resistance of materials to penetration. R. D. Collins and W. H. Kinard. N.A.S.A. T.N. D-238. May 1960.
The dependence of projectile penetration in semi-infinite solid targets has been investigated for targets and projectiles of steel, aluminium, copper, and lead. The penetration data have been presented as a function of the maximum momentum per unit area of the projectile and the crater volumes as a function of the kinetic energy possessed by the projectile.—(21.2).
Some experiments concerning subsequent yield surfaces in plasticity. H. G. McComb. N.A.S.A. T.N. D-396. June 1960.
Combined load tests were made on seven thin-walled 2014-T4 aluminium alloy tube specimens. The secondary yield surface is outlined in the normal-stress-shear-stress plane for an initial loading in pure tension. Discussion is presented of significant changes in the shape of the stress-strain curves obtained from tests of the thin-walled tube specimens.—(21.2.2×33.2.2×33.2.4.3).

MATHEMATICS

See also MECHANICAL ENGINEERING

Investigation of third-order contactor control systems with two complex poles without zeros. I. Flugge-Lotz and T. Ishikawa. N.A.S.A. T.N. D-428. June 1960.
An investigation of third-order contactor control systems is reported. The transfer function of the uncontrolled system has one real and two conjugate complex poles and may have zeros. In general, it is assumed that all poles have negative real parts; however, cases with positive real parts of the complex poles are included.—(22.1).

Response of some linear systems to random forces with reference to aircraft buffeting. E. W. Graham and A. M. Rodriguez. Douglas Report S.M.-14517. Sept. 1952.—(22.2×1.6.3).

MECHANICAL ENGINEERING

Study of effect of a non-Newtonian oil on friction and eccentricity ratio of a plain journal bearing. G. B. DuBois et al. *N.A.S.A. T.N. D-427. May* 1960.
The effects on the friction and oil film thickness of a journal bearing of using a non-Newtonian lubricating oil whose viscosity decreases at high rates of shear are investigated experimentally and analytically.—(23.1×14.2).

Analysis and computer study of an adaptive control system. D. A. Dawson. N.R.C. Report MK-4. Sept. 1959.
The concept of total cost or economic penalty is formulated for adaptive control of regulators. The cost is assumed to be a function of the error and the manipulated variable, although the function need not be known *a priori*. A circuit is then described which will optimise the system *i.e.* vary the gain of the controller so as to bring it towards the value associated with the minimum total cost. The results of an experimental study describe the effect of variations of the parameters of the adaptive circuit on the over-all behaviour.—(23×18.1×22).

The optimum thrust tilting-pad bearing. L. Floberg. Inst. Machine Elements. Chalmers Univ. of Tech. Rep. 12. 1960.
Ootimum conditions for thrust tilting-pad bearings are considered. The choice of the number of pads and the width-length ratio when the load capacity, the angular velocity and the minimum permissible oil film thickness are given is discussed. A schedule for design calculation is made. Tables and charts of the bearing quantities are given.—(23.1).

The two-groove journal bearing, considering cavitation. L. Floberg. Inst. Machine Elements. Chalmers Univ. of Tech. Report 13. 1960.
The 360° two-groove journal bearing with ring- or pressure-lubrication is treated. Tables and charts for bearing design and schedules for calculation of the bearing quantities are given. Consideration is taken of cavitation of the oil when calculating the power loss. The viscosity is assumed to be constant. It is shown how to design bearings with a minimum of power loss at certain given conditions. Two optimum design examples are given.—(23.1).

METEOROLOGY

See also MATERIALS

Determination of atmospheric density at a height of 430*KM by the sodium vapour diffusion method. I. S. Shklovshii and V. G. Kurt. R.A.E. Lib. Trans.* 896. *May* 1960.
The method of determining upper-atmospheric density from the rate of expansion of a glowing cloud of sodium is described. Details are given of the results of an experiment performed with a high-altitude rocket in September 1958.—(24×8.1).

MISSILES

See AERODYNAMICS—COMPRESSIBLE FLOW
HYDRODYNAMICS
THERMO-AERODYNAMICS
AIRCRAFT OPERATION

NAVIGATION

See AIRCRAFT OPERATION